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BY- COOK, DESMOND L.
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DESCRIPTORS- *MANAGEMENT, RESEARCH PROJECTS, *PROGRAM ADMINISTRATION, *PROGRAM PLANNING, *SYSTEMS CONCEPTS, *CRITICAL PATH METHOD, COLUMBUS, OHIO, PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT)

THE PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT) USED IN PROJECT MANAGEMENT WAS DESCRIBED FOR THE EDUCATIONAL RESEARCH AND DEVELOPMENT COMMUNITY. THE MANAGEMENT PROCESS IN EDUCATIONAL RESEARCH AND DEVELOPMENT WAS REVIEWED, AND THE NEED FOR NEW TECHNIQUES WAS IDENTIFIED. THE BASIC CONCEPTS, TECHNIQUES, AND METHODS OF PERT WERE COVERED UNDER (1) BREAKDOWN OF WORK STRUCTURE, (2) NETWORK DEVELOPMENT, (3) ACTIVITY TIME ESTIMATION, (4) NETWORK TIME CALCULATIONS, (5) PROBABILITY ASPECTS OF PERT, (6) REPLANNING OF THE PROJECT, AND (6) PERT/COST INTRODUCTION. POSSIBLE APPLICATIONS OF PERT TO VARIOUS TYPES OF EDUCATIONAL RESEARCH AND DEVELOPMENT ACTIVITIES INCLUDED ILLUSTRATIONS OF MODEL WORK BREAKDOWN STRUCTURES AND NETWORKS FOR EACH APPLICATION. PRACTICAL CONSIDERATION AS TO THE ACTUAL IMPLEMENTATION OF PERT ON A PROJECT WAS ALSO PROVIDED. (JM)

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PERT

Applications In Education

DESMOND L. COOK

School of Education
The Ohio State University

(Preliminary draft of a manuscript to be published in monograph form by the U.S. Office of Education. Not to be reproduced in whole or in part without prior permission of the author or the USOE.)

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Preface

The purpose of this monograph is to disseminate to the educational community the basic concepts and principles of a recently developed project management information system entitled Program Evaluation and Review Technique - or PERT. It is anticipated that creating awareness of the technique's existence will lead to its adoption as a project planning and control tool for research and development activities. The monograph is not designed to be an exhaustive treatment of the technique. Its primary goal is to establish sufficient knowledge about the technique that individuals desiring to implement PERT on a project may do so. A selected bibliography is presented for persons wishing to know more about the technique.

The preparation of this monograph was made possible through a contract with the Cooperative Research Branch of the U. S. Office of Education which permitted the author to study the technique. The specific activity funded was Project E-019, "The Applicability of PERT to Educational Research and Development Activities" which was carried out from March 1, 1964, to August 31, 1965.

I am indebted to many organizations, both military and civilian, for assistance in shaping up the basic concepts and principles of PERT. Special thanks are expressed for the continued interest in and cooperation with the project provided by the PERT Orientation and Training Center, Washington, D.C.

I am particularly indebted to Dr. Earl Stahl, Assistant Project Director, for his assistance in preparing a draft of the chapter on basic characteristics of PERT as well as the many activities carried out during the course of the project. A special acknowledgement is made to Mr. Ian Seeds, Missile Program Control Manager, Columbus Division of the North American Aviation Company for giving the project the benefit of his extended experiences in PERT application and for his critical and detailed review of the manuscript in its draft form. Thanks are also due to my colleagues at The Ohio State University for their assistance in helping us study the technique by direct application to on-going projects. I would also like to extend my appreciation to Mr. Terry Owen, Research Assistant, who became an expert on PERT computer programs, and to Mrs. Judy Eby, Project Secretary, for typing the final manuscript. To all of the above persons and agencies I owe many thanks. The ultimate blame for inaccuracy and inconsistency is the author's alone.

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Chapter 1

The Management Process in Educational Research and Development

Introduction

The two decades since the termination of World War II have witnessed increased emphasis on research and development activities in almost all phases of the economy. There has always been research and development in an advancing technological society but it was during the years of conflict that the initiation of broad large-scale research projects (e.g., Manhattan project) dealing with complex and often relatively new concepts and ideas began to reach fruition. While industry has primarily been concerned with research and development as it relates to the development of new products and improvement of existing products or creating new markets, the emphasis given to basic research has been much less. The government, on the other hand, has utilized both basic and applied research and development for the design of new military weapon systems. More recently, there has been a developing government-industry partnership for the purpose of conducting large-scale research and development activities.

The advent of the new "look" in research and development activities created many problems for those charged with the responsibility of bringing projects to successful completion. In general, the achievement of a stated goal depends upon how well the end objective can be specified, the experiences one has had in accomplishing such goals in the past, and the application of resources. The successful completion of a vacation trip to a specified site has a greater possibility of success because we have done this task beforehand. The successful completion of an activity such as putting a man on the moon, on the other hand, has a low initial probability because of our relative lack of knowledge of how to do it even though the goal is well defined. The probability of successful completion of both increases with the excellence of the "road map" used to accomplish the objective.

Numerous techniques and systems have been developed in the past to assist those persons bearing the responsibility for project completion to do a better job of reaching the goal. While these techniques have been generally successful when applied to relatively small-scale projects and/or activities where production is rather routine, such management systems become limited in their usefulness for the new large scale and highly complex, both quantitatively and qualitatively, research and development projects.

Because of problems of increasing difficulty in properly managing all of the activities associated with the development of a new military weapons system using the traditional techniques, project managers began to look around for a technique which would enable them to handle the problems associated with unknown and complex nature of the multitude of tasks to be done. In 1958, the Special Projects Office of the Department of the Navy developed a system designed to provide for more effective project control. The basic need for such a system appeared when the Navy and the prime contractors were faced with managing a project having many dissimilar operations widely dispursed geographically. Different contractors with different management systems had to be correlated for management purposes. This new management system or technique was titled Program Evaluation and Review Technique, to which the acronym PERT has been applied. Since numerous historical accounts of the development of the technique exist, no recounting of events will be repeated here. Historical reports of PERT development appear in the summary reports prepared by the Special Project Office of the U. S. Navy (24,25) or in an article by Malcolm and others (14). PERT has been found to be a methodology for planning many diverse activities regardless of the nature of the project. It has been found to be useful in small as well as large projects. Because of the reported successful application in widely diverse activities (e.g., house construction, missile development, Broadway plays), its potential usefulness to the management of educational research and development activities was recognized.

The purpose of this monograph is to present to the educational research and development community the basic principles of PERT along with suggestions for utilizing the technique for the management of research and development projects in the field of education. The management of educational research and development activities appears not to have been a topic of great concern until the amount of government and private support for research programs and projects increased tremendously during the past decade. The introduction of federal programs such as the Cooperative Research Program of 1954 and the National Defense Education Act of 1958 provided funds for a wide variety of research and development programs. In addition, numerous private philanthropic organizations such as The Ford Foundation provided large amounts of funds. Large appropriations are being made for research and development activities under the new vocational education legislation passed by Congress in 1963 and The Elementary and Secondary Education Act of 1965.

The problems faced by the government-industry research and development managers are now being faced by persons occupying similar positions in education. It would follow that perhaps solutions developed by the former would be applicable to the management problems of educational research and development.

To understand the purpose and nature of a management information system such as PERT, it is necessary to review briefly some basic concepts and principles of the management process. The remainder of this chapter will be devoted to presenting a brief discussion of a definition of management, a description of the management process, and the characteristics of a good management system. A rationale for applying management concepts to educational research and development projects and programs will conclude the chapter.

The Nature of Management

Management is defined here as the art and science of planning, organizing, motivating, and controlling human and material resources and the interaction between them in order to attain a predetermined objective. As viewed here, management is a broader activity than that of administration. The former focuses on the process of decision-making which is considered as one of the tasks of management while the latter focuses on the implementation of policy and the provision of administrative support to research programs. The director of an educational research and development project is basically a manager. He alone is responsible for all decisions about the use of poeple and resources to reach project objectives. One or more offices on the campus can provide facilities to assist him with the administrative matters but such offices cannot direct his decision-making. Such offices as computer centers, publications offices, and travel bureaus are facilitative in that they provide basic data for the decision-making process.

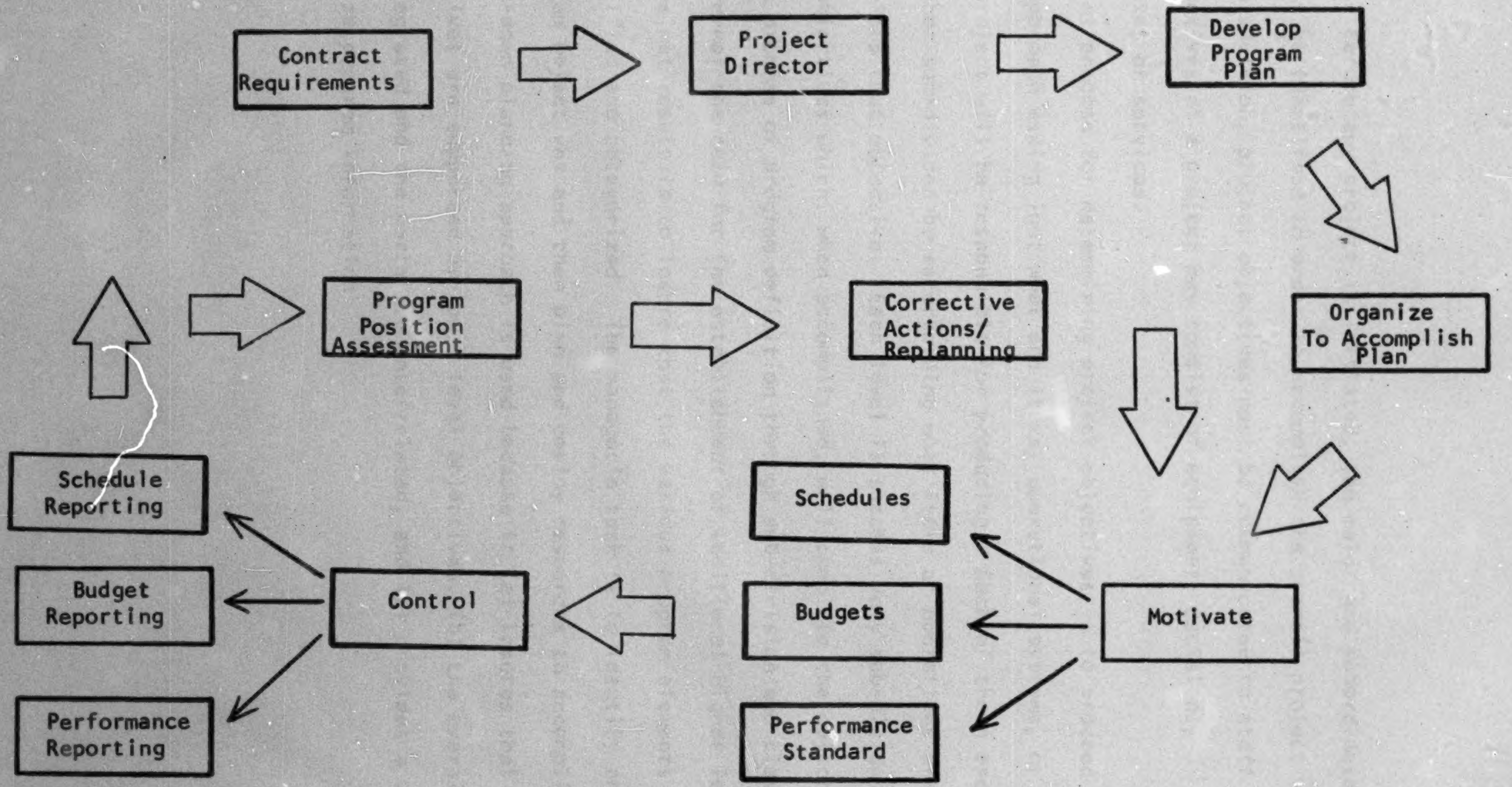
The employment of the term management in educational circles had not had wide acceptance in education. Yet, the types of activities that an educational personnel are often called upon to perform are more appropriately categorized as managerial than administrative. The management function has always been performed in educational institutions as has been well pointed out by Hungate (9). It has not been properly labeled as such. Individuals such as the presidents and deans are managers to the degree that they plan the course of future events and activities, organize to carry out their plans, motivate people to carry out the plans, and they assess progress and control the results by management actions. Under this conceptualization, managers have line responsibilities while administrators have staff responsibilities.

The Management Process

The process involved in moving from initiating the project or program start to the production of the final end objective consists of several broad procedural steps (12). While there may be some variation due to the uniqueness of an individual project, the general activities involved in the management process are as illustrated in Figure 1.

Insert Figure 1 about here

Figure 1. The Management Cycle


Contract Requirements
Project Director
Develop Program Plan
Organize To Accomplish Plan
Motivate
Schedules
Budgets
Performance Standard
Control
Schedule Reporting
Budget Reporting
Performance Reporting
Program Position Assessment
Corrective Actions/ Replanning

Planning - Before any project is initiated, the major and subordinate objectives must be identified in order to accomplish the overall project objective. In addition, project objectives must be communicated to staff members. Objectives of a project may consist of equipment, decisions, facilities, data, or services.

The general process for determining project objectives is to proceed by a "top-down" approach asking just what end items, operational systems, or services the project will be responsible for producing. Each of these end items are further sub-divided by ascertaining what items or operations are needed to complete that objective. Each level is successively sub-divided into its sub-objectives which, when accomplished, will complete the objective above it. The process of program definition through sub-division and classification may reveal the need for the establishment of additional higher level end items. The net result is to insure that the various program elements are properly identified and categorized. The manager's task is to identify and organize program objectives and then plan and employ resources to accomplish them. The top-down planning approach is used because it (a) insures that program objectives are supported by lower level objectives, (b) the overall project is integrated and the parts are interrelated, and (c) provides a useful way to summarize program information.

Organizing - The successful accomplishment of a total project depends fundamentally upon the establishment of the plan designed to reach major and minor objectives. The accomplishment of a program goal can be reached by any one of several possible plans but there does have to be some type of plan. Planning is interpreted here to include not only the careful definition of program end objectives but also the effort involved in determining the specific work or tasks to be done and establishing the sequence and dependency existing among the tasks along with the establishment of performance standards or quality control levels for the several tasks. The goal is to achieve an optimum balance between schedule, costs, and performance requirements.

Once the plan has been established, calendar dates and times can be established for the start and completion of each element of the plan. The process of assigning such dates and times within allowable time periods is referred to as scheduling. Once duration times have been allocated for the plan, manpower requirements may then be determined. Scheduling is considered to be fundamentally different from planning in that planning considers the logic or sequencing of activities while scheduling specifies durations and periods of calendar time in support of the program plan.

Motivating - After the steps of planning and organizing have been accomplished, it is necessary to motivate the personnel to carry out the work to be done. This management step includes directing assignment of tasks to be accomplished by departments or persons, communicating project goals, assessing staff morale, providing competent leadership, and similar actions. Good management involves communication between all levels of management, from the project down to the line supervisor and back. Management efforts to involve concerned departments and personnel in the planning and organizing functions pays off in terms of increased morale and better production.

Controlling - Once the project plan is organized and the project or program is underway, management must be kept fully informed of the status of the work on a regular basis and upon request. Deviation from the program plan must be called to the attention of managment along with recommendations for corrective action. Controlling is the process of managment actions in response to deviations from the plan.

One major problem in project control is to know or to identify those project elements or tasks which require managment's attention. Not all problems are of equal intensity. Proper project control involes utilization of the "mangement by exception" principle. Under this principle, the best use is made of management's competencies by directing them to the crucial problems and not to minor or less crucial problems properly solved by subordinates.

After the manager makes a decision about a solution to the problem, the original plan might have to be modified to incorporate any new elements or revision of old elements which result from the decision. The general success of the replanning effort will be noted by the degree to which the new plan can be carried out in subsequent time.

Integrated Management System

Any system or technique designed to aid management in carrying out the management must enable the manager to manipulate three common dimensions of a project if he is to accomplish successfully the end objective. These dimensions are (a) time, (b) cost (or resources) and (c) performance.

The time dimension is basically those aspects of the project relating to the time each work element is expected to consume plus the total time for completion of the project. Time overruns on individual project activities can delay the completion of the project. Time underruns on the other hand, while leading to early completion of the project might reflect inefficient application of program resources and/or inadequate program definition.

The cost dimension involves the allocation of resources (men, materials, equipment, money) to accomplish the various tasks of the project. Consumption of materials and manpower at a rate faster than planned might result in a cost overrun or over-expenditure of budget for the total project. On the other hand, it might be more feasible to spend faster to complete the project with no adverse effects on the project.

The performance dimension refers essentially to the levels of quality stated as end objective specifications. For example, the developmental specifications for a test might require that it have a test-retest coefficient of .90 based upon a 1% national sample of high school seniors.

Generally the project manager must manipulate the time and cost dimensions in order to accomplish the specified technical performance level. Successful accomplishment of performance levels may require the consumption of additional time and costs resulting in overruns for these items on the project. Rigid limitations on the time-cost dimensions, such as exist in fixed-price contracts, may result in a decision to lower performance specifications in order to stay within funding consideration.

A total and integrated management system must provide useful information on a timely basis to the appropriate management level. This information must depict comparisons between actual status and planned status in the areas of schedule, cost, and performance. In addition, good analysis of problem situations by staff can greatly increase the effectiveness of line management.

Applying Management Concepts to Education

The question might well be raised, why should the educational community be interested in the application of management concepts to the research and development effort? In addition to the lack of experience in handling the research and development effort previously cited, other reasons can be set forth. Several of these are discussed below without any attempt to place them in an order of importance.

Research and development projects possess certain common characteristics regardless of the specific nature of each project. Each research and development project has a starting and end point with the latter usually being carefully delineated or specified. To reach the end objective, a series of tasks or activities have to be accomplished in some prescribed order. Since many persons and/or organizations are involved in carrying out the tasks, some type of coordinate effort must be made in order to assure achievement of the final goal. Further, a great deal of uncertainty exists with regard to the nature of the tasks to be performed and the time to accomplish them. Such projects are often commonly referred to as "once-through" activities since the chances are the particular project involved will not be repeated except perhaps as it is developed into a routine and production type activity. Further, guidelines in terms of the amount of historical and background information and standards available in establishing the time and method of reaching the goal are lacking in view of the fact the activity has not been previously performed.

It is perhaps quite easy to recognize that military and industrial projects evidence the above characteristics but it is equally true that many educational research and development activities also evidence these same characteristics. There are many kinds of activities, such as developing a curriculum, constructing a test, making a school survey, which have these characteristics. A system or technique which will help us to overcome the problems associated with the natural characteristics of research and development projects would appear to be quite useful in helping administrators and other interested personnel in achieving stated goals.

Perhaps a more cogent reason that project characteristics for examining management concepts centers around the evolutionary, and perhaps even revolutionary, change taking place with regard to the funding of the educational research and development effort. During the past decade the amount of research support available for educational activities has increased rather tremendously. Hungate (9) noted that in 1954 there was $30,000,000 available from various sources, $50,000,000 available in 1958, and in 1963 almost a $1,000,000,000. Recent legislation by the Congress has further increased the amount of funds available.

While the increase in research support is generally accepted as being desirable, certain restrictions are an inherent part of securing these funds. First, agencies allocating the funds usually require some type of project proposal along with a budget statement plus progress reports at selected intervals. By various means, projects are monitored from the beginning or initial funding through to the termination of the final objective which often includes the submission of a final technical report.

The large amount of funds available for research and development has also brought about a change in the nature of the projects. Projects are becoming much larger and complex in scope and often involve a research team as opposed to a single researcher. It is not uncommon for government-funded educational research and development projects to be of three to five years in duration, involve a staff of ten to fifteen persons, and cost in excess of $500,000. The project director assigned the responsibility for properly accomplishing the goals of the research under such a situation becomes a manager as well as a researcher. Whatever his own personal desires might be, increasing amounts of time are spent in the management process as described above. Some aspects of his responsibilities are assumed by campus agencies such as research foundations but in the long run they serve primarily as facilitative agencies which can contribute significantly to the effectiveness of the researcher. It would appear that some type of system which would assist managers of large projects, as well as projects of a smaller magnitude in terms of time and costs, might be quite useful in order that more time can be spent doing research and less time managing.

As noted above, one feature of the increased support for educational research involves the preparation of a research proposal. Proposal preparation usually follows a format prepared by the funding agency and includes such sections as the purpose of the research, the general procedures to be followed, a statement of needed staff personnel, and an estimated budget. The preparation of proposals generally satisfies such requirements but when the project gets underway many of the difficulties encountered occur because of inadequate project planning in the proposal preparation stage. Interdependencies between project objectives are not made adequately clear nor are key milestone events or tasks clearly identified. Personnel requirements are often made without realistically relating project activities to personnel skills and/or time required to accomplish a particular job. Since good management is facilitated by good planning, it would appear that knowledge of some type of a system designed to produce better planned project proposals would result in their being better managed and thus, increasing the probability of successful completion of project objectives.

Summary

The educational research and development effort has accelerated significantly during the past decade due to influences such as increased government funding caused by increasing public concern over educational problems. In order that the greatest good can come from this effort, it would appear that adequate management of educational research and development must take place. It is true that educators have had some experience in handling research and development activities but only of a limited nature has tended to occupy a minimum role in the past. Now, such activities have suddenly assumed a very major role. Since many of the problems encountered and to be encountered have been experienced by other areas of the society involved in research and development, it would seem logical that educators could derive benefit from the study of problems encountered and problem solving techniques developed in these other areas. These other areas soon discovered that the management of the research and development effort could not be handled by previously developed techniques and something new was required. The purpose of this monograph is, therefore, to present a new technique developed for one aspect of research and development - that of project management. Specifically, attention will be given to the presentation of a management information system known as Program Evaluation and Review Technique, or PERT.

Chapter II

Basic Characteristics of PERT

The purpose of this chapter is to present the general features of PERT in order to acquaint the potential user with the basic concepts, techniques, and methods of the system. The utilization of these features will vary from situation depending upon the complexity of the project and the purpose for applying PERT.

The following topics are covered in this chapter: work breakdown structure, network development, activity time estimation, network time calculations, probability aspects of PERT, replanning the project, and an introduction to PERT/COST.

Work Breakdown Structure

The use of PERT as a technique for project management begins with the definition of project objectives. The Work Breakdown Structure which reflects a top-down approach to planning should be used as the initial step in applying PERT. This process consists of subdividing the total project into smaller and more easily managed program elements. The process of subdivision and classification continues until the desired level of detail is reached.

A Work Breakdown Structure for a simple survey project is shown as Figure 2. The major units of work of the project are objectives, design, data analysis, and documentation.

Insert Figure 2 about here

Figure 3 illustrates the further subdivision of the design until along with a classification of the work at the next level down for the design subdivision labeled as Sample.

Insert Figure 3 about here

Figure 2. Major Work Units of a Simple Survey Project

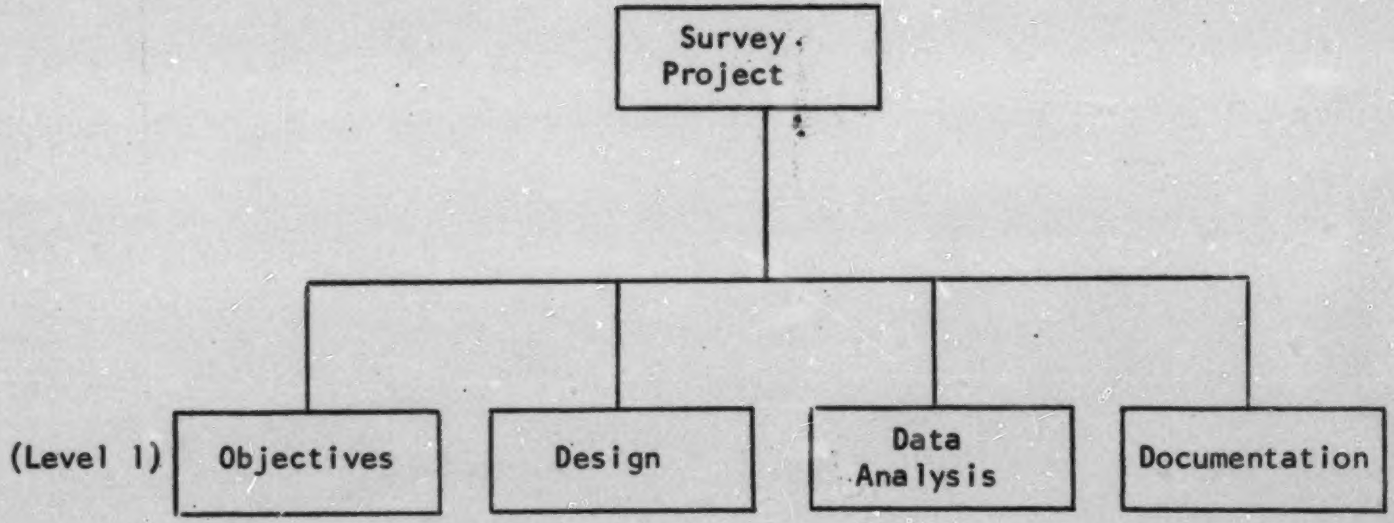
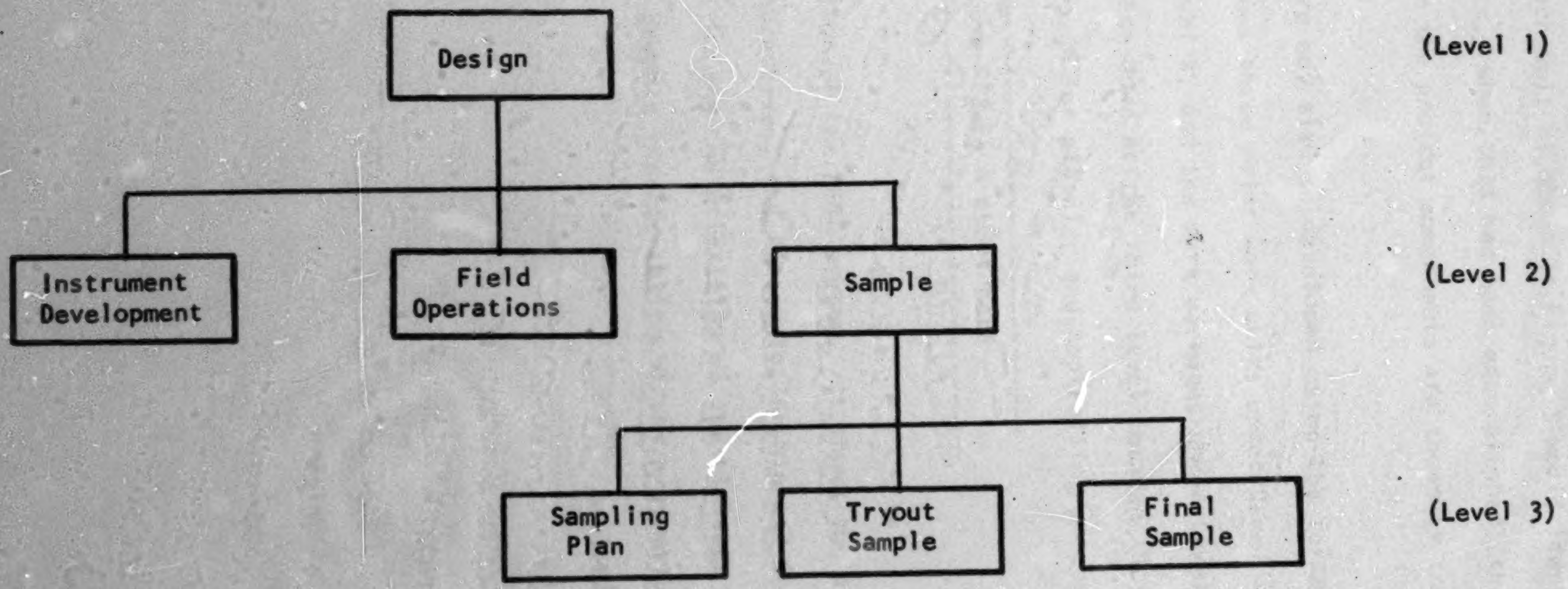

Survey Project
(Level 1)
Objectives
Design
Data Analysis
Documentation

Figure 3. Subdivision of a Work Unit in a Work Breakdown Structure


Design
(Level 1)
Instrument Development
Field Operations
Sample
(Level 2)
Sampling Plan
Tryout Sample
Final Sample
(Level 3)

A further breakdown of each unit as shown in Figure 3 would identify the components of each of the units. When this has been accomplished, the dependency relationships existing between the project components are shown by the use of a network.

A Work Breakdown Structure may also be developed using the format illustrated in Figure 4. This example shows three major work units under Level 1, the components of each unit under Level 2, and the work packages under Level 3. Some of the components are not broken down at the third level because they are considered sufficiently small enough for planning and controlling purposes at Level 2.

Insert Figure 4 about here

Network Development

A network is the foundation of the PERT system. It shows the plan established to reach the project objectives, the interrelationship and interdependencies of the project elements, and the priorities of the elements of the plan. In essence, the network is a graphic representation of the project plan.

Figure 4. Work Breakdown Structure for a Simple Survey Project

	LEVEL 1	LEVEL 2	LEVEL 3
Survey Project	Objectives	Problem Delimitation Hypotheses Data Paradigms	
	Survey Design	Instrument Development	Item Construction Format Design Direction Preparation Cover Letter Preparation Tryout Item Revision Final Form Production
		Field Operations	Travel Arrangements Interviewer Selection Reliability Check Follow-up Procedures
		Sample	Sampling Plan Tryout Sample Final Sample
	Data Analysis	Coding System Data Reduction Statistical Tests Interpretation	
	Documentation	Narrative Tables/Graphs Bibliography	

A network is made up of events and activities. Events represent the start or completion of an activity and do not consume time, personnel, or resources. Events are instantaneous points in time when an action has been started or completed. Examples of event descriptions are:

a. start sample selection
b. start test item analysis
c. start writing curriculum guide
d. complete statistical analysis
e. complete enrollment survey
f. complete literature review

Events are graphically represented on networks by a variety of symbols such as circles, squares, and rectangles. Usual practice is to use circles for events and squares or rectangles for milestone or important events.

An activity is a task or job in the project requiring the utilization of personnel and resources over a period of time to complete. An activity describes the work needed to proceed from one event to another. Activity descriptions must be as definitive as possible in order that work responsibilities can be assigned, realistic time estimates can be made for the duration of the activity, and the users of the network can understand what each activity represents.

Examples of activity descriptions are:

a. select statistical technique
b. keypunch data cards
c. write questionnaire items
d. hire new staff
e. install audio-visual equipment
f. design test manual

An activity is represented on the network by an arrow connecting one event with another. Dummy activities, those which do not consume time or resources, are represented by dotted arrows. An example of a simplified network is shown in Figure 5.

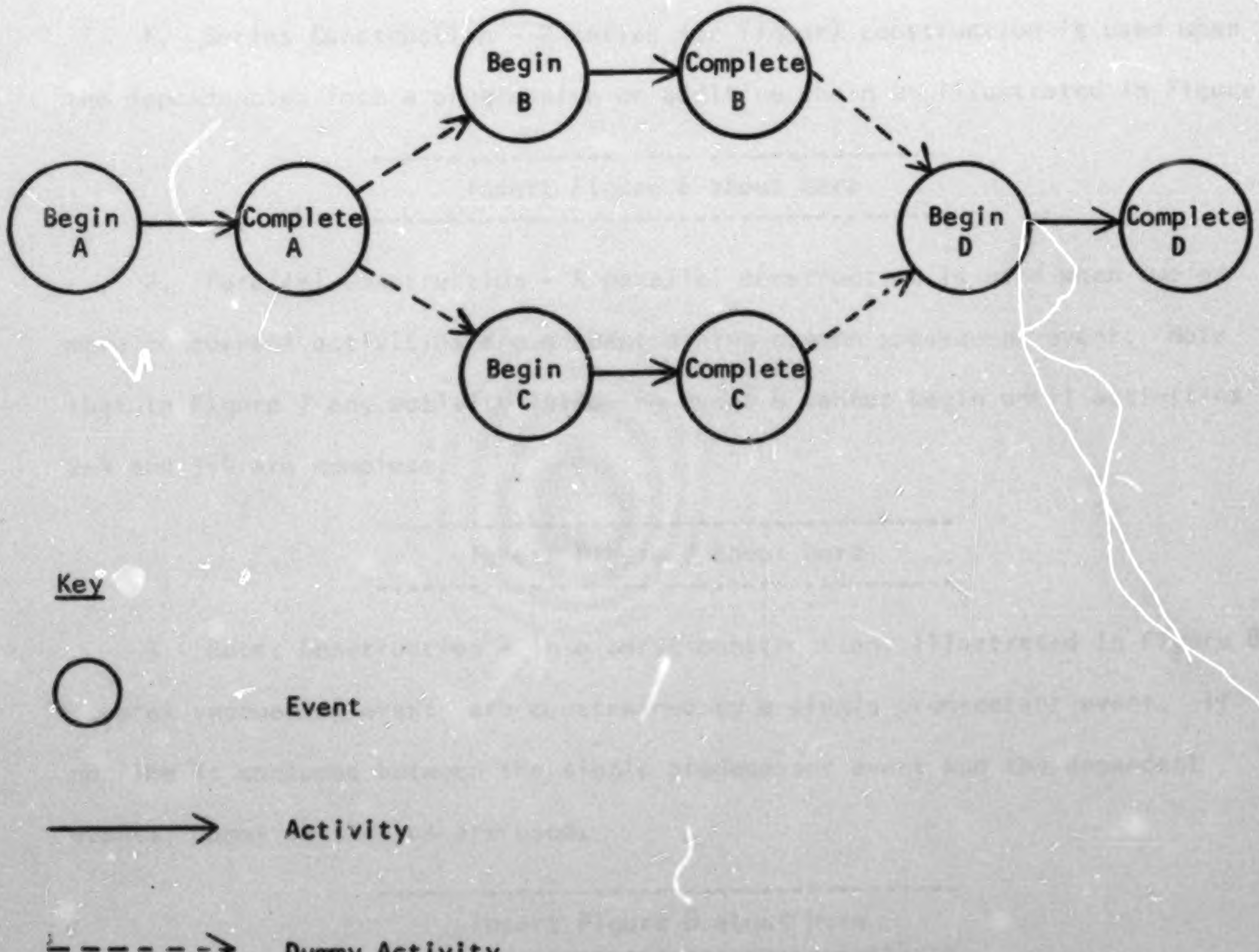
Insert Figure 5 about here

The construction of a network requires that certain rules be observed in order that the logic of the network is clear and precise. A network may have to be reviewed several times to be sure that violations of the rules are not present.

The first step in constructing a network is to place the project work units, as identified in the Work Breakdown Structure, in their logical order. Supporting events and activities are then added to form the network.

The question of whether a network is constructed from the beginning to the end event (left to right or forward), or from the end to the beginning event (right to left or backward), somewhat depends upon the uniqueness of the project being networked. If the elements of the project are fairly well-known and defined, a forward type construction might be employed. On the other hand, a backward construction starting from the final event forces the user to consider what activities and events must take place before the project objectives can be accomplished. Whichever method is used for constructing the network, the flow of the network always moves from left to right.

Figure 5. A Simplified Network Showing Events, Activities, and Dummy Activities


Begin A
Complete A
Begin B
Complete B
Begin C
Complete C
Begin D
Complete D
Key
Event
Activity
Dummy Activity

Dependency and constraint are fundamental concepts of network construction. A dependency or real constraint exists when one activity or event cannot take place until the events and activities preceeding it have taken place. Planned constraints, however, are those event/activity relationships which have been established as a desirable but not absolutely necessary program relationship. Various types of dependency and constraint situations are illustrated below.[1]

1. Series Construction - A series (or linear) construction is used when the dependencies form a progressive or additive chain as illustrated in Figure 6.

Insert Figure 6 about here

----

2. Parallel Construction - A parallel construction is used when two or more concurrent activities are a constraining common subsequent event. Note that in Figure 7 any activity following event 4 cannot begin until activities 2-4 and 3-4 are complete.

Insert Figure 7 about here

----

3. Burst Construction - In a burst construction, illustrated in Figure 8, several succeeding events are constrained by a single predecessor event. If no time is consumed between the single predecessor event and the dependent events, dummy activities are used.

Insert Figure 8 about here

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[1] The illustrations and accompanying explanations are reproduced by permission of General Precision, Inc., Commercial Computer Division, 100 East Tujunga Avenue, Burbank, California.

Figure 6. Series Construction

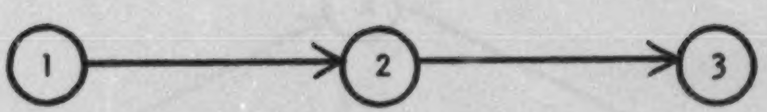


Figure 7. Parallel Construction

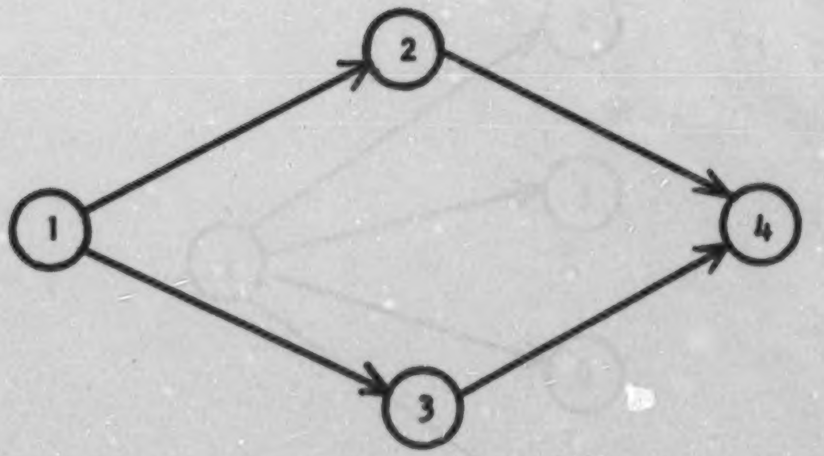
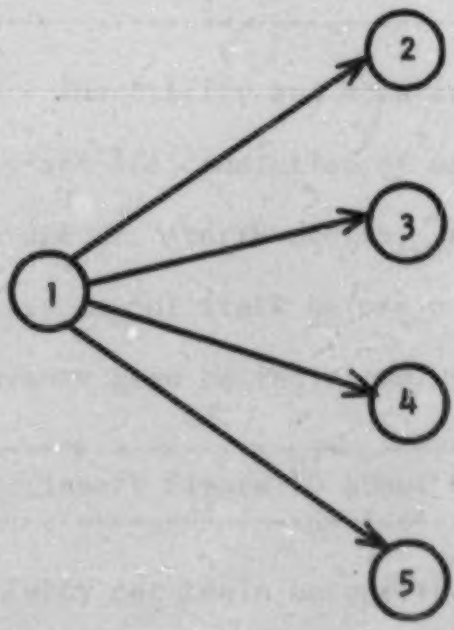


Figure 8. Burst Construction



4. Merge Construction - The merge construction in Figure 9 illustrates a single successor event being dependent upon the completion of several preceding events. Dummy activities may also be used if no time is involved.

Insert Figure 9 about here

---

5. Network Clarity - The clarity and accuracy of a network depends upon the illustration of the start and completion of each activity in the network. This is done through the use of "start" events, "complete" events, and dummy activities. If an activity cannot start before a preceding activity is finished, only start or complete events need be indicated as shown in Figure 10.

Insert Figure 10 about here

However, if one activity can begin before the preceding activity is completed, both the start and completion events must be shown as in Figure 11.

Insert Figure 11 about here

---

6. Multiple Start or Final Events - A network usually has only one starting and one final event. While multiple start and end events are sometimes required, it is general procedure to tie multiple start and/or end events to a single dummy event with a dummy activity arrow for purposes of clarity as illustrated in Figure 12.

Insert Figure 12 about here

Figure 9. Merge Construction

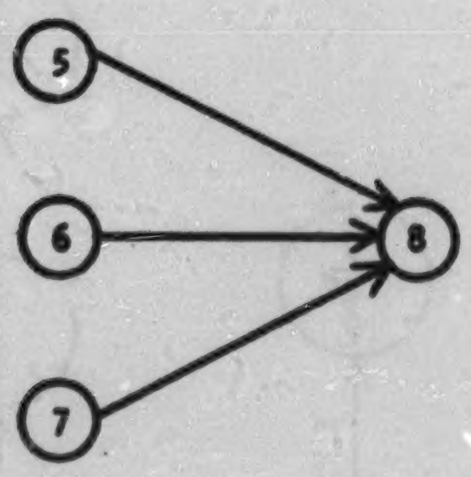


Figure 10. Designation of Start and Completion of Activities for Network Clarity

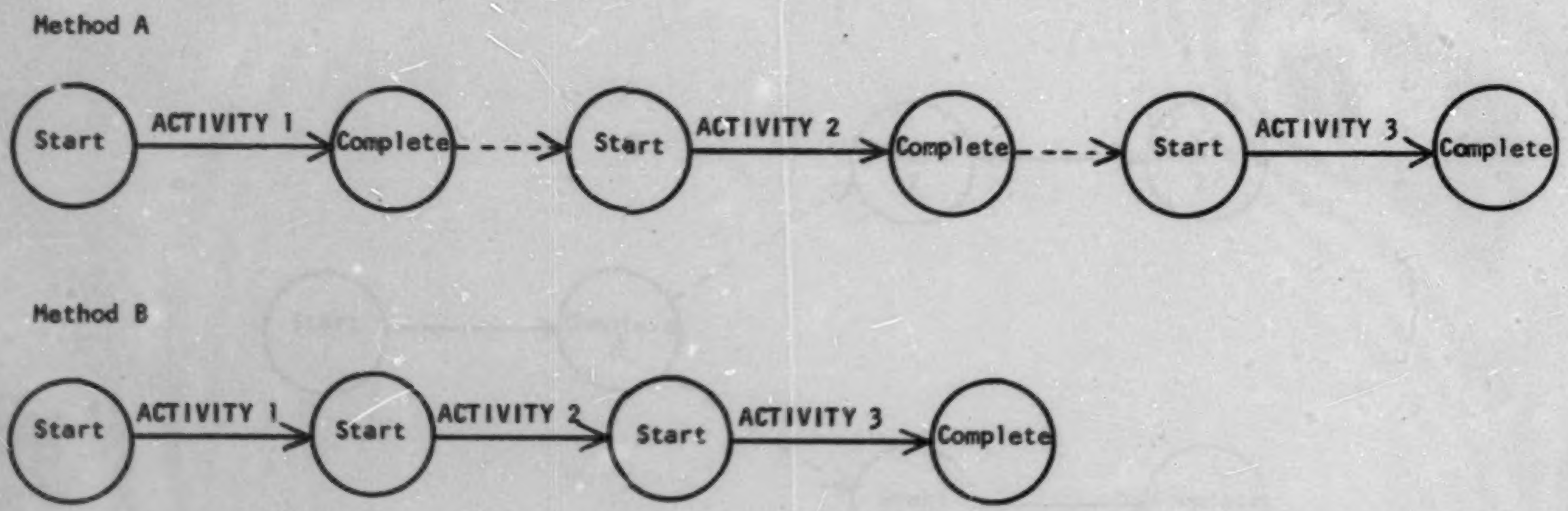

Method A
Start
ACTIVITY 1
Complete
Start
ACTIVITY 2
Complete
Start
ACTIVITY 3
Complete
Method B
Start
ACTIVITY 1
Start
ACTIVITY 2
Start
ACTIVITY 3
Complete

Figure 11. Illustration of Required Completion of Other Activities Before the Start of Subsequent Activities

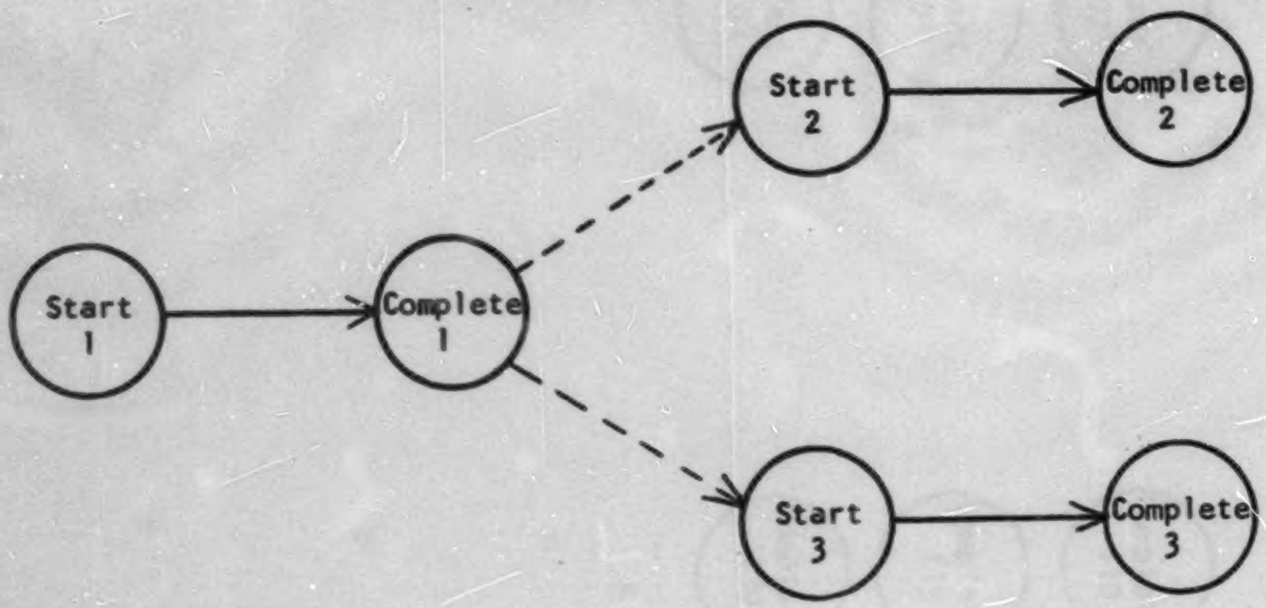
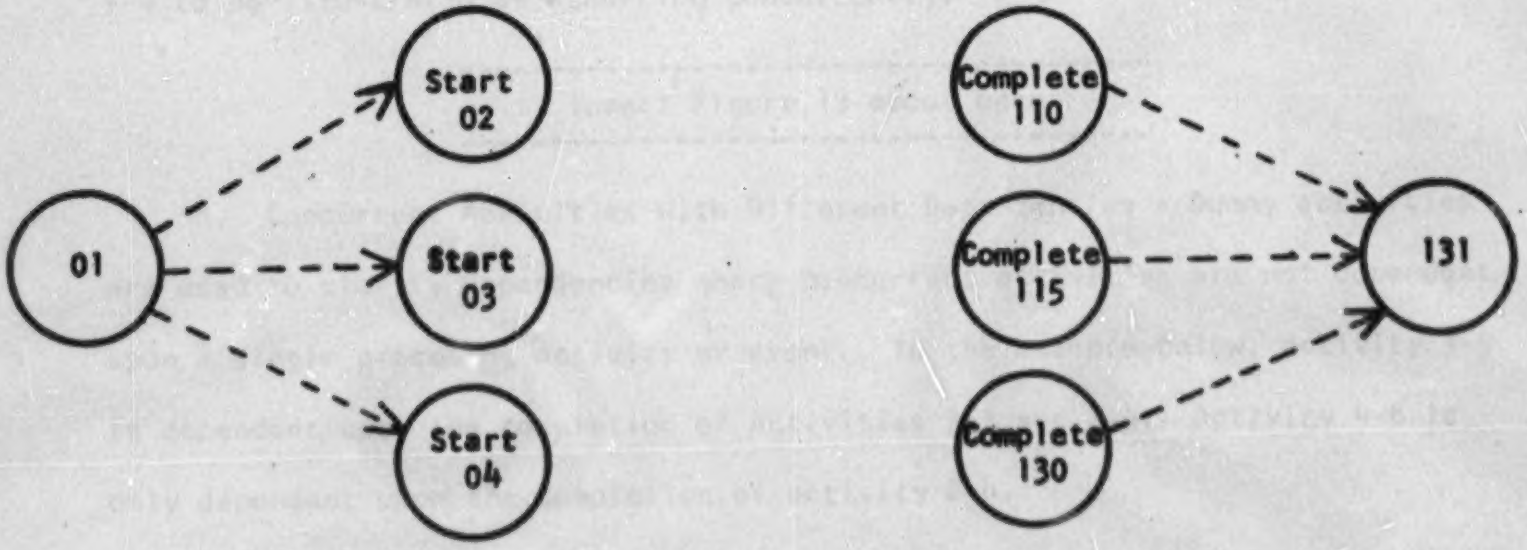

Start
1
Complete
1
Start
2
Complete
2
Start
3
Complete
3

Figure 12. Illustration of Dummy Start and Final Events


01
Start 02
Start 03
Start 04
Complete 110
Complete 115
Complete 130
131

7. Concurrent Activity Construction - Only one activity may be shown between two events. Where concurrent activities are being carried out between common events, dummy activities must be used to set off the activities. In Figure 13, activities 1-2 and 1-3 are dummies allowing activities 1-4, 2-4, and 3-4 to be illustrated as occurring concurrently.

Insert Figure 13 about here

---

8. Concurrent Activities with Different Dependencies - Dummy activities are used to clarify dependencies where concurrent activities are not dependent upon a single preceding activity or event. In the example below, activity 3-5 is dependent upon the completion of activities 1-3 and 2-4. Activity 4-6 is only dependent upon the completion of activity 2-4.

Insert Figure 14 about here

In addition to the network construction techniques illustrated, some further rules imposed on networking are listed below.

1. An event is unique and can occur only once in a network.
2. There can be no feedbacks or loops in the network. That is, the network cannot return to an event that has been accomplished.

A general procedure in the PERT technique is to identify the network paths by the events through which they pass. Figure 15 illustrates a network with three paths, i. e., 1-2-6, 1-4-6, and 1-3-5-6.

Insert Figure 15 about here

Figure 13. Concurrent Activity Construction

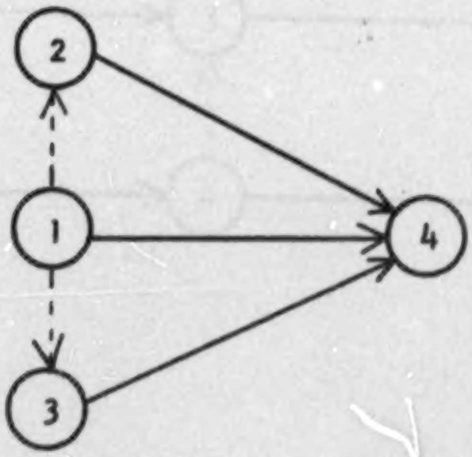


Figure 14. Concurrent Activities with Different Dependencies

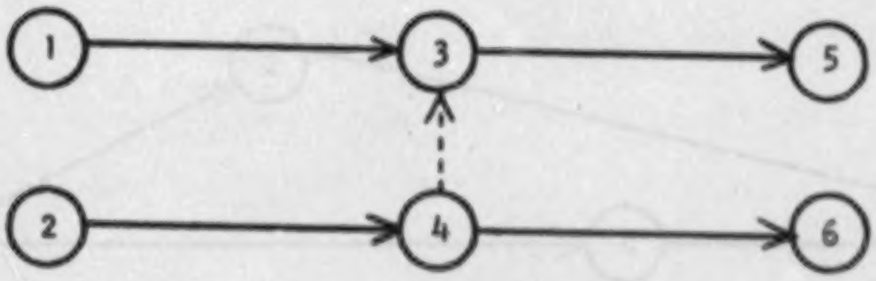
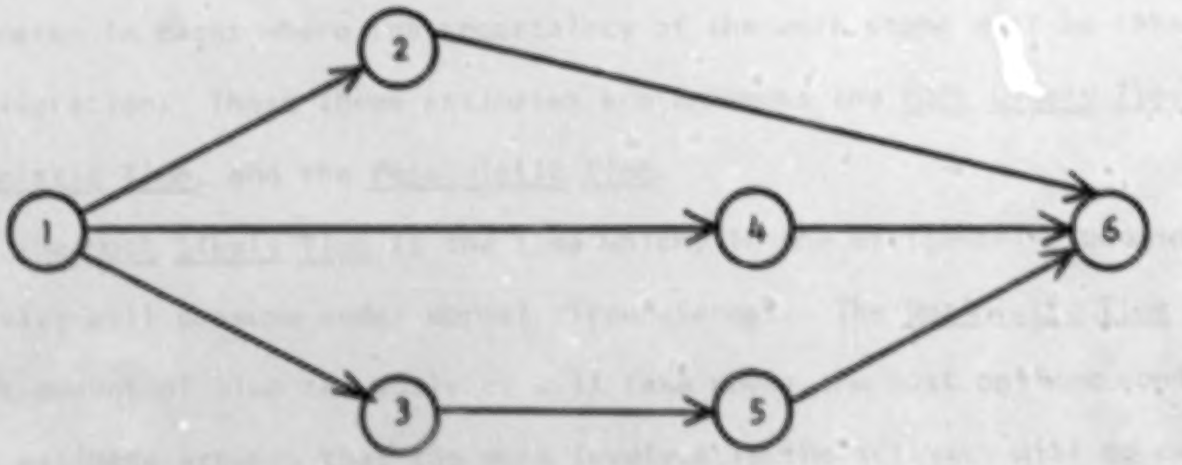


Figure 15. Illustration of Network Paths



Activity Time Estimation

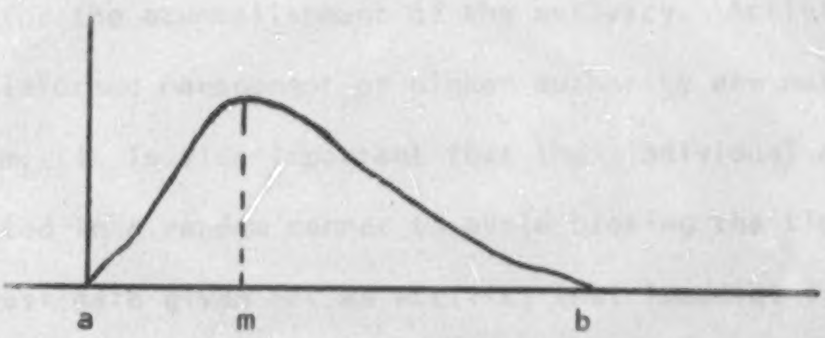
After the network has been constructed and the logic of the plan approved by the users, estimated times to complete the work are secured for each of the activities in the network. A single time estimate may be secured for the expected duration of the activity but the more usual procedure is to secure three time estimates in cases where the uncertainty of the work scope must be taken into consideration. These three estimates are known as the Most Likely Time, the Optimistic Time, and the Pessimistic Time.

The Most Likely Time is the time which, in the estimator's judgment, the activity will consume under normal circumstances. The Optimistic Time is the least amount of time the activity will take under the most optimum conditions. This estimate assumes that the work involved in the activity will go exceptionally well. The assumption underlying the optimistic time estimate is that an activity would have no more than one chance in a hundred of being completed in this time. The Pessimistic Time assumes that anything that can go wrong will go wrong, short of acts of God. This estimate should take into account the most adverse conditions including the possibility of failures occurring which cause the work to start over again. The time estimate also has no more than one chance in one hundred of occurring.

The basic statistical assumption of PERT is that the three time estimates form a Beta distribution. Experience has substantiated this assumption. Figure 16 presents an example of a Beta curve with an Optimistic (a) and Pessimistic (b) time forming the range of the distribution and the Most Likely Time (m) appearing at the mode of the curve.

Insert Figure 16 about here

Figure 16. Beta Distribution of the Three Time Estimates



There is no standard procedure regarding the order in which the three time estimates must be made. Most users of PERT, however, estimate the Most Likely Time followed by the Optimistic and Pessimistic Times.

It is important that activity duration times be secured from the person who is responsible for the accomplishment of the activity. Activity time estimates imposed by uninformed management or higher authority are not consistent with the PERT system. It is also important that the individual activities on a network be estimated in a random manner to avoid biasing the time estimate of an activity by the estimate given for an activity that immediately precedes or succeeds it.

The validity of the time estimates will depend to a large degree on how well defined the activity is that is being time estimated. Since the validity of the output data from the PERT system depends directly on the validity of the time estimates, activity definition becomes quite important. Vague or gross activity definitions are difficult to time estimate.

The uniqueness or newness of the work involved will also affect the time estimates for the activity. If an activity has been done many times before, the estimates may have a very small range, such as 4-5-6. It is even possible that the values of the three estimates may be the same if the nature and duration of the activity are well established. On the other hand, activities that are unique and have been seldom, if ever, performed will be characterized by time estimates with wide ranges, such as 2-6-12. This uniqueness of tasks and activities is inherent in many research and development efforts and the three time estimates are intended to allow for this uncertainty. Other conditions generally followed in estimating activity times are:

1. Time estimates assume that resources (including personnel) will be available on a normal basis or as requested in the project proposal.
2. Time estimates are based on a five-day work week and are established by weeks and tenths of weeks. A time estimate of 0.1 week would be equivalent to 1/2 of a day, an estimate of 0.2 would be equivalent to 1 day, and so forth. Other time units may be used, but the week and tenth of week are the most common.
3. Schedule or calendar dates should have no effect on the initial time estimates. By ignoring present calendar dates, the estimator avoids biasing his estimates in favor of these dates.

Network Time Calculations

After the three time estimates have been secured, average or Expected Elapsed times are calculated for each activity using the following formula:

$$t_e = \frac{a + 4m + b}{6}$$

In the formula, t_e stands for the Expected Elapsed time, a for the Optimistic time, m for the Most Likely time, and b for the Pessimistic time.

The total values entered in the formula thus become six ($1a + 4m + 1b$), making it necessary to divide the sum of the values by six.[2] An example of using the three time estimates in the above formula is:

$$a = 5$$

$$m = 10$$

$$b = 14$$

$$t_e = \frac{5 + (4)\ (10) + 14}{6}$$

$$t_e = \frac{59}{6}$$

$$t_e = 9.8$$

The calculated t_e values are customarily rounded off to the nearest tenth of a week.

---

[2] A discussion of the origin and validity of the formulas for the mean and variance based upon the assumed Beta distribution appears in MacCrimmon and Ryavec (13) and hence, such considerations are not presented in this monograph.

After the Expected time has been computed for an activity, it is also possible to obtain an estimate of the variability of the time estimates associated with that activity. The range of time spread is represented by the standard deviation of the activity times. The formula for finding the standard deviation is:

$$\sigma_{t_e} = \frac{(b-a)}{6}$$

substituting the values used in the above example,

$$b = 14, \ a = 5$$

$$\sigma_{t_e} = \frac{(14-5)}{6}$$

$$\sigma_{t_e} = 1.5$$

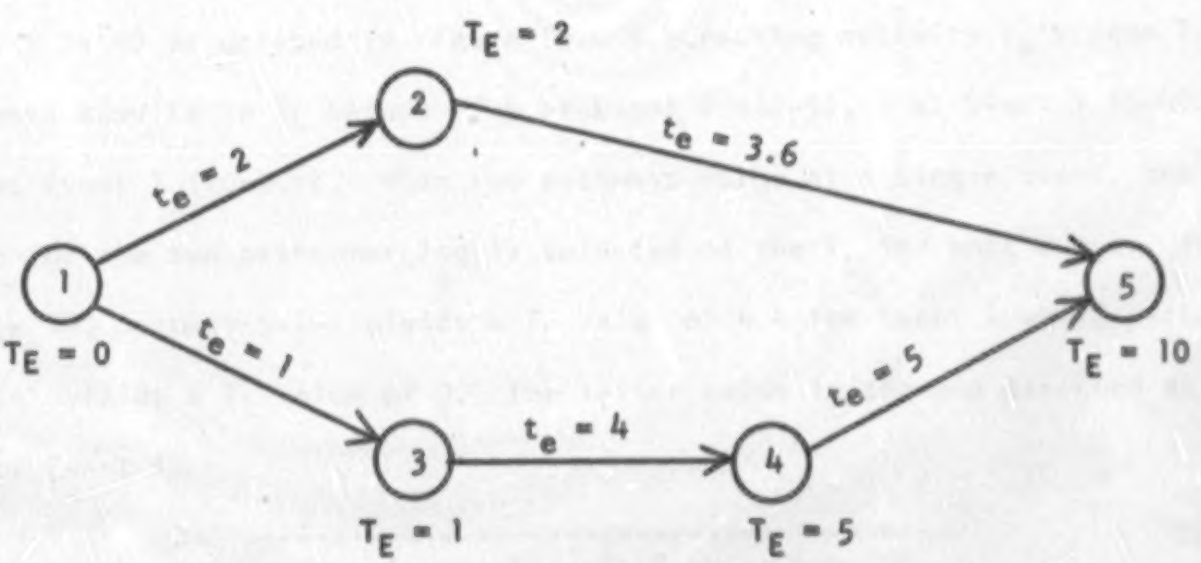
We can use the obtained value to estimate the probability that an activity will be completed within the range of the estimated times by employing normal curve concepts. For our example, there is a 68 per cent chance that the activity will be completed within 1.5 weeks either side of the Expected time (t_e), a 95 per cent chance that the activity will be completed within 3 weeks either side of t_e, and a 99 per cent chance that the activity will be completed within 4.5 weeks of t_e. Additional explanation of the statistical assumptions is presented in several of the references listed in the Annotated Bibliography.

The Expected Elapsed time (t_e) provides a means of determining the earliest and latest times that any given event can take place. The earliest time is designated as the Earliest Expected Time and is represented by the symbol T_E while the latest time is designated as Latest Allowable Time and represented by the symbol T_L.

Figure 17 presents an example of computing T_E for network events. Since there are no activities or events preceding Event 1, the T_E at Event 1 is 0. To find the T_E for any subsequent event, the t_e's are summed along the longest path to the given event. For example, the t_e for Activity 1-2 is 2, therefore, the T_E for Event 2 is 2. At Event 5 there are two possible T_E's since there are two activity paths merging at this event. The rule for selecting the T_E for an event where two or more activity paths merge is to select the one that yields the largest value. In the example, activity path 1-2-5 has a total t_e value of 5.6 while path 1-3-4-5 has a total t_e value of 10. Therefore, the T_E at Event 5 is 10 weeks.

Insert Figure 17 about here

Figure 17. Illustrations of Computing T_E's for Network Events


$T_E = 2$
2
$t_e = 2$
$t_e = 3.6$
1
5
$T_E = 0$
$t_e = 1$
$T_E = 10$
$t_e = 5$
3
$t_e = 4$
4
$T_E = 1$
$T_E = 5$

The Latest Allowable Time (T_L) for each event is computed by beginning with the final or end event and subtracting the t_e's of the preceding activities. The T_L is the latest time by which an event must occur without causing a delay in the accomplishment of the final event. For purposes of illustration, the value of 10 weeks was assigned as the T_L value at Event 5. The T_E value for Event 5 is 10 as derived in Figure 17. Subtracting activity t_e's from T_L of 10 weeks results in T_L values of 5 at Event 4 (10-5), 1 at Event 3 (5-4), and 6.4 at Event 2 (10-3.6). When two pathways merge at a single event, the smallest value for the two paths merging is selected as the T_L for that event. In Figure 18, pathway 5-2-1 yields a T_L value of 4.4 for Event 1 while pathway 5-4-3-1 yields a T_L value of 0. The latter value is the one assigned as the T_L for Event 1.

Insert Figure 18 about here

Having found the T_E and T_L for each event, it is now possible to compute the amount of slack associated with these events. The amount of slack for each event is determined by subtracting the T_E from the T_L. Figure 19 presents the computation of slack using the T_E and T_L values illustrated in Figures 17 and 18.

Insert Figure 19 about here

Figure 18. Illustration of Computing T_L's for Network Events

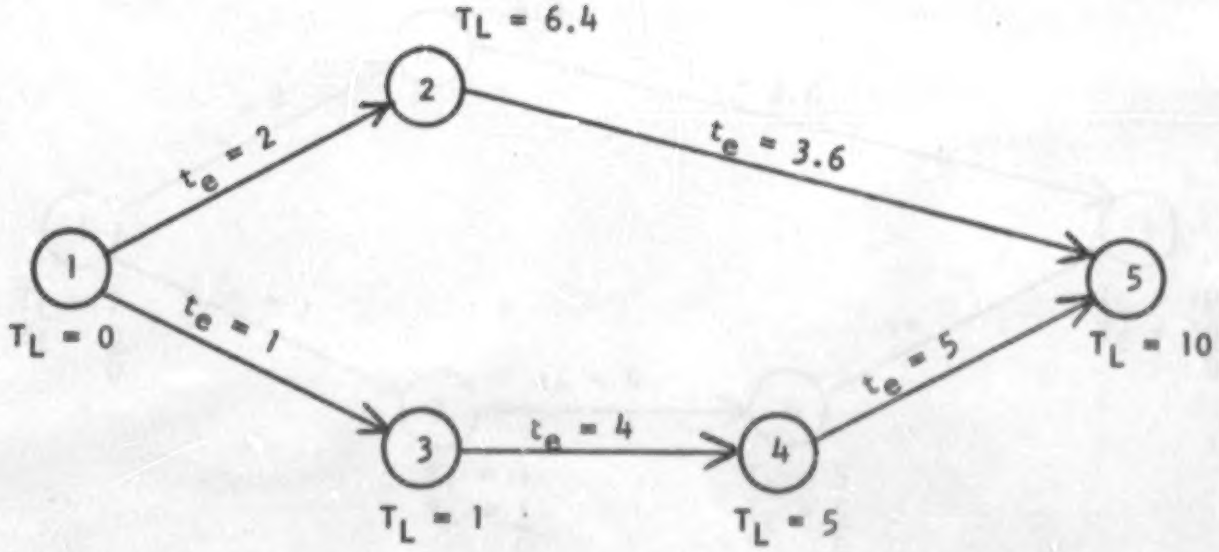
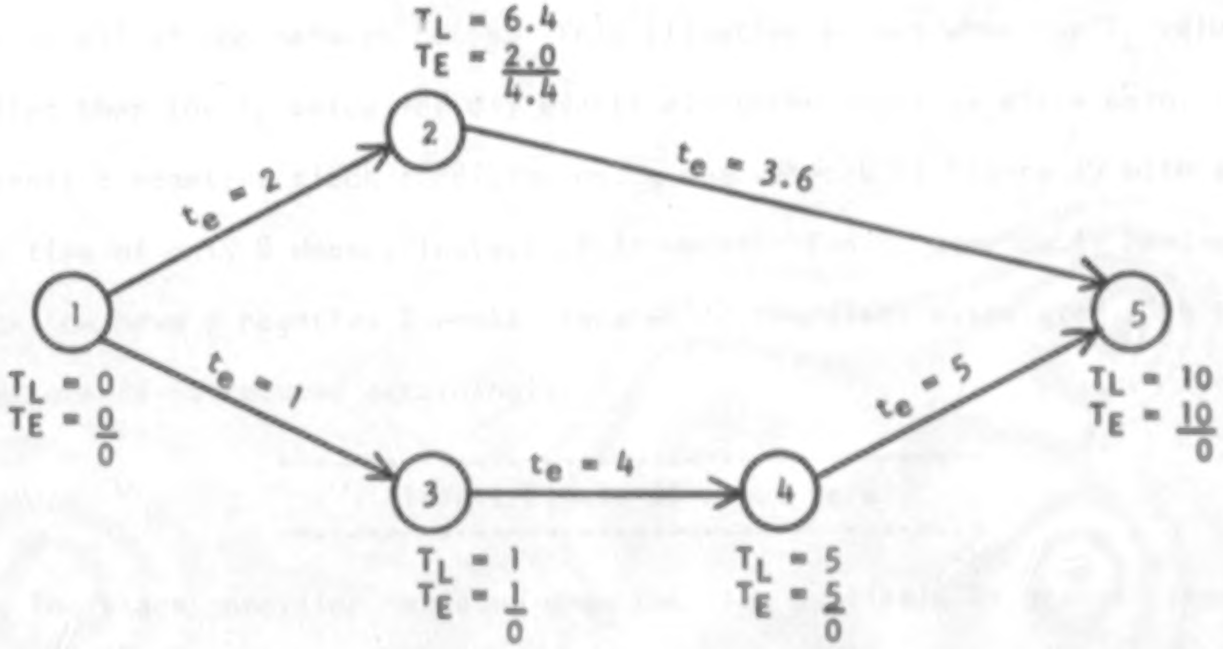

$T_L = 6.4$
2
$t_e = 2$
$t_e = 3.6$
1
$T_L = 0$
$t_e = 1$
5
$T_L = 10$
$t_e = 5$
3
$t_e = 4$
4
$T_L = 1$
$T_L = 5$

Figure 19. Illustration of Computing Slack


1
2
3
4
5
$T_L = 6.4$
$T_E = 2.0$
4.4
$t_e = 2$
$t_e = 3.6$
$t_e = 1$
$t_e = 4$
$t_e = 5$
$T_L = 0$
$T_E = 0$
0
$T_L = 1$
$T_E = 1$
0
$T_L = 5$
$T_E = 5$
0
$T_L = 10$
$T_E = 10$
0

In many project situations, the amount of time available for the completion of the project is either less or more than the time estimated to do the project in the desired manner as represented by the T_E for the final event. When the time available is less than the estimated time, negative slack will exist along some or all of the network paths. This situation arises when the T_L value is smaller than the T_E value for all events along the negative slack path. Figure 20 presents a negative slack condition using the network in Figure 19 with an available time of only 8 weeks, instead of 10 weeks. Events previously having zero slack now have a negative 2 weeks slack while the slack associated with the other events is reduced accordingly.

Insert Figure 20 about here

The slack condition arising when the time available is greater than the estimated time is referred to as positive slack. Using the same illustration as before but now assuming an available time of 15 weeks instead of 10, it can be seen in Figure 21 that large amounts of positive slack exist along the two pathways of the network.

Insert Figure 21 about here

Figure 20. Illustration of Negative Slack

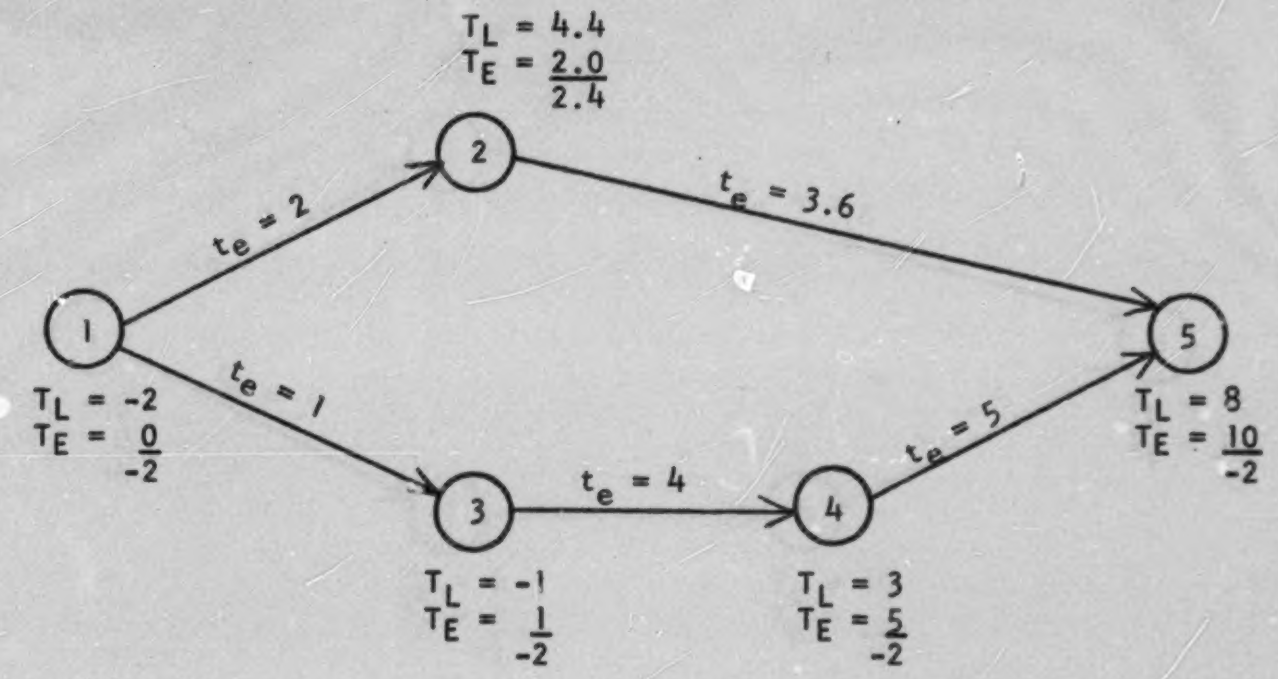
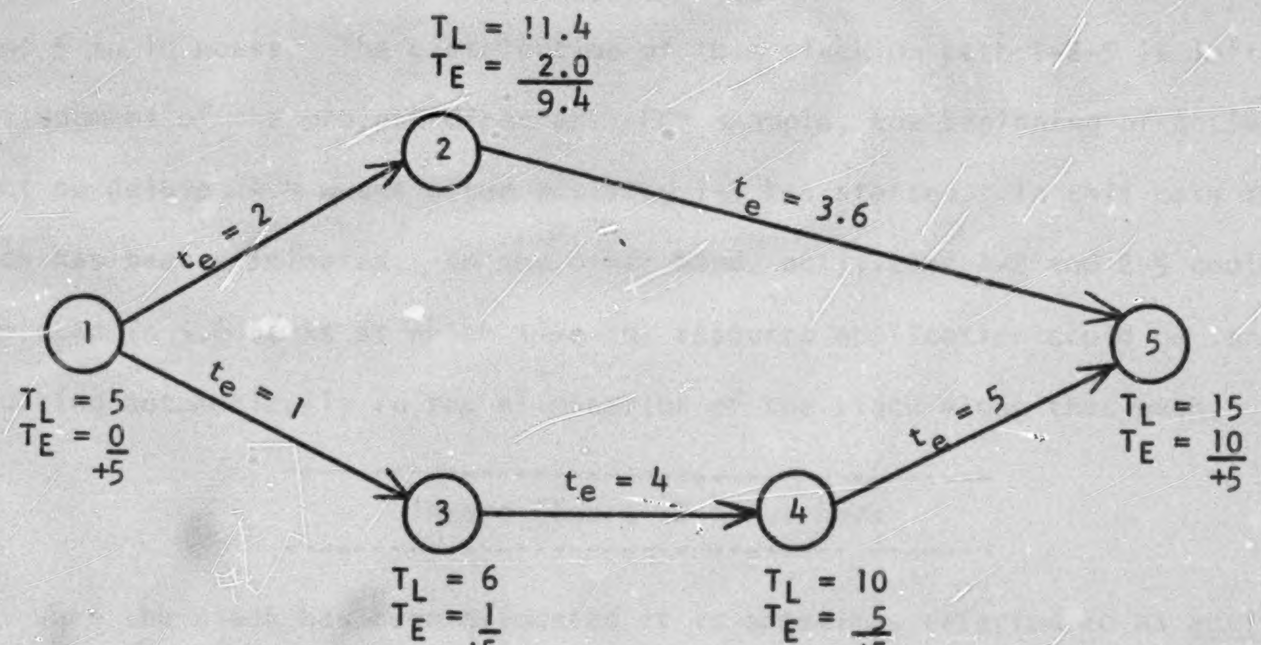

T_L = 4.4
T_E = 2.0
2.4
2
t_e = 2
t_e = 3.6
1
t_e = 1
5
T_L = -2
T_E = 0
-2
T_L = 8
T_E = 10
-2
t_e = 5
t_e = 4
3
4
T_L = -1
T_E = 1
-2
T_L = 3
T_E = 5
-2

Figure 21. Illustration of Positive Slack


$T_L = 11.4$
$T_E = 2.0$
9.4
2
$t_e = 2$
$t_e = 3.6$
1
$T_L = 5$
$T_E = 0$
+5
$t_e = 1$
5
$T_L = 15$
$T_E = 10$
+5
$t_e = 5$
$t_e = 4$
3
$T_L = 6$
$T_E = 1$
+5
4
$T_L = 10$
$T_E = 5$
+5

The amount of slack for the events on path 1-3-4-5 is 0. Therefore, the activities on this path must be completed within their t_e values if Event 5 is to take place 10 weeks after Event 1. Path 1-2-5 has 4.4 weeks of slack, indicating that activities 1-2 and 2-5 can be delayed 4.4 weeks and still reach Event 5 in 10 weeks. The distribution of this slack on path 1-2-5 is left to the judgment of the project director. For example, the beginning of activity 1-2 might be delayed 4.4 weeks after activity 1-3 has started. In this case the slack has been eliminated. On the other hand, activities 1-2 and 2-5 could be completed in 5.6 weeks at which time the resource application could be terminated resulting automatically in the elimination of the slack along that path.

Insert Figure 22 about here

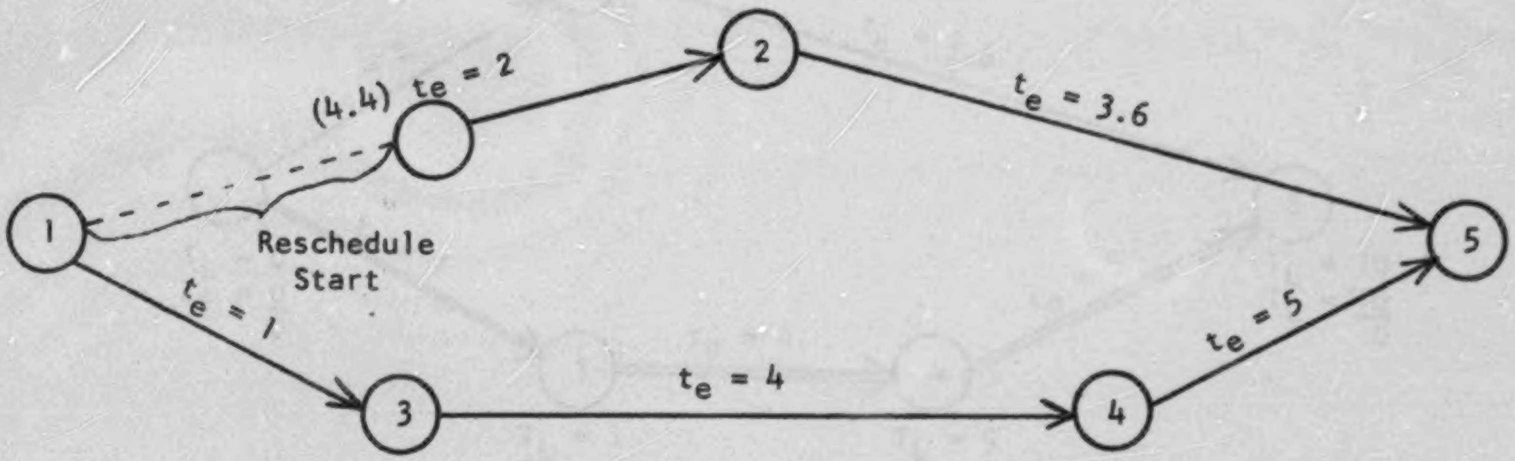
When the slack has been allocated it is sometimes referred to as activity slack to differentiate it from event slack.

The slack in the network also identifies the Critical Path since the Critical Path is defined as that path from the beginning to the ending event which has the least amount of positive slack or the greatest amount of negative slack. It may also be defined as the longest or most time consuming path through the network. The Critical Path is graphically displayed on the network by a double or heavier line as illustrated in Figure 23.

Insert Figure 23 about here

Figure 22. Alternative Allocation of Slack on a Network Path

Alternative A


1
2
3
4
5
(4.4) $t_e = 2$
$t_e = 3.6$
Reschedule Start
$t_e = 1$
$t_e = 4$
$t_e = 5$

Alternative B

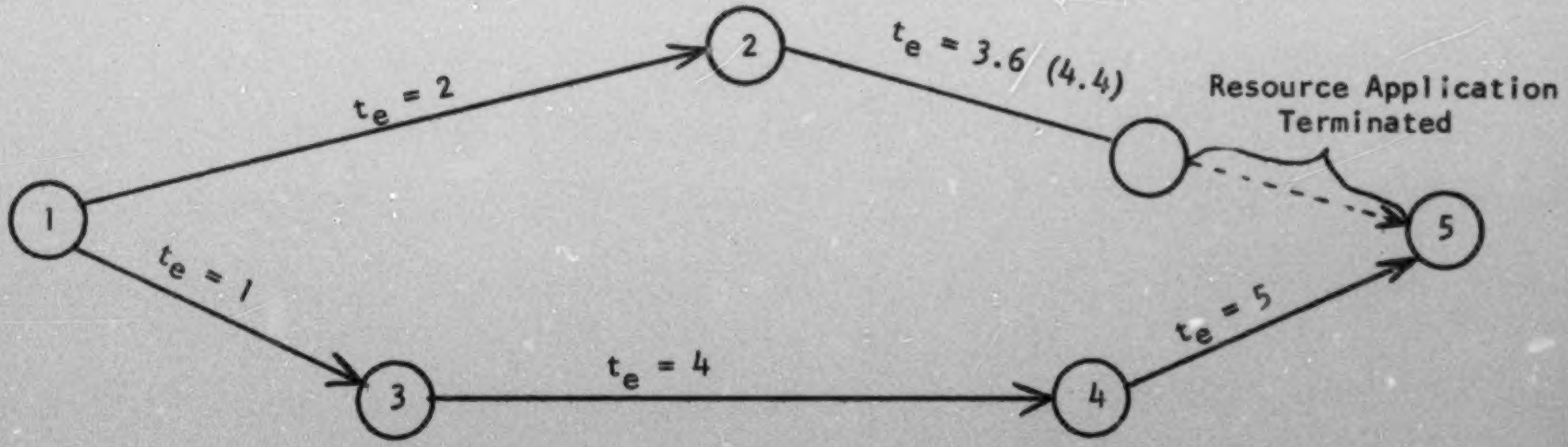
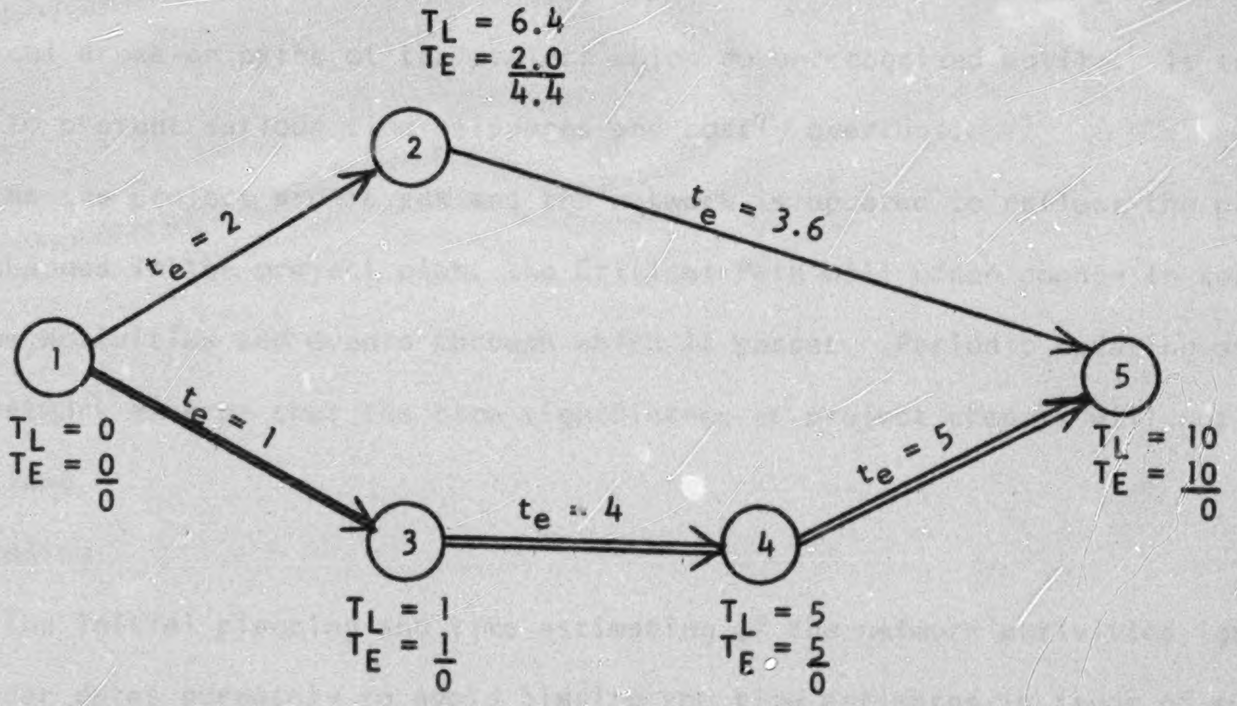

1
2
3
4
5
$t_e = 2$
$t_e = 3.6$ (4.4)
Resource Application Terminated
$t_e = 1$
$t_e = 4$
$t_e = 5$

Figure 23. Illustration of Critical Path


$T_L = 6.4$
$T_E = \underline{2.0}$
4.4
2
$t_e = 2$
$t_e = 3.6$
1
$T_L = 0$
$T_E = \underline{0}$
0
$t_e = 1$
3
$t_e = 4$
4
$t_e = 5$
5
$T_L = 10$
$T_E = \underline{10}$
0
$T_L = 1$
$T_E = \underline{1}$
0
$T_L = 5$
$T_E = \underline{5}$
0

The activities on the Critical Path in the network provide the most rigid time constraint on the completion of the project. The attention of the project director must be focused primarily on this path rather than upon paths that are less critical. This feature of PERT provides the means of identifying the critical areas or paths of the project which go unrecognized until it is too late to prevent serious time slippages and costly overruns.

As the project progresses and the network is updated to reflect the progress and changes in the project plan, the Critical Path will often change in terms of the activities and events through which it passes. Periodic updating of the network assures that the time significance of project changes will not go unnoticed.

Scheduling

The initial planning and time estimating of the network activities ignores calendar dates purposely to avoid biasing the time estimates in favor of such calendar dates. While the time estimates provide a framework to begin the scheduling process, they do not provide all the information necessary for scheduling.

The scheduling process is initiated by assigning scheduled dates (T_S) to significant events in the network. The scheduled date assigned to the end event must be the same as or earlier than the T_E for the end event. A higher authority (e.g., the funding agency) asks the project to be completed in 8 weeks. The project director, however, can assign a completion date of 6 weeks in order to provide for unforseen problems. In PERT terminology a date imposed by an authority from outside the project is called a Directed Date (T_D) in order to distinguish it from a scheduled date established by the project director. The scheduled date for the final event in the network becomes the T_L for the end event and is used to determine the T_L's for all other events.

Further scheduling is done by assigning scheduled times ($\underline{t_s}$) to the activities in the network. The t_s may be the same, less, or greater than the expected time (t_e). The value of the t_s is largely dependent upon the experience and knowledge of the project director about the activity. A scheduled earliest expected date ($\underline{S_E}$) and a scheduled latest allowable date ($\underline{S_L}$) may be computed for the network events in the same manner as the event T_E's and T_L's are computed using the t_s values. The project schedules should be disseminated to the personnel involved in the project at the earliest possible time.

There are several considerations involved in scheduling a project. One such consideration is real constraints imposed by the availability of personnel, equipment, facilities, and other resources. For example, the use of elementary or high school students as subjects in a project is generally restricted to the months between September and June. The constraint imposed by the availability of the subjects in such a situation would be an important scheduling consideration.

Another consideration involved in scheduling is the desire to optimize personnel utilization in order to avoid overtime or idle time. For example, project management attempts to level manpower requirements by taking advantage of network slack in order to avoid severely fluctuating manpower requirements. This consideration of personnel utilization is important because the services of specialized personnel in an educational research and development project are often costly. If the nature of the project is such that these specialized services could be spread over the life of the project or a large part of the project rather than being peaked at some point in the project, the project director may be able to devise a more realistic budget and a more realistic utilization of project personnel. In some cases, the nature of a project may require specialized personnel and/or intermittent help, creating necessary high and low periods of manpower application. The utilization of PERT enables the project director to schedule well in advance personnel required to satisfy peak requirements.

The limitations of time and budget imposed by the funding agency will also affect the scheduling of the project. For example, a project proposal may request a January 1 start date. If the funding agency imposes a different start date, such as April 1, the project director is faced with the task of internally scheduling his project to meet the external scheduling requirement. Additionally, the funding agency or "customer" may impose other requirements that will affect the project schedule. For example, in a proposal to build a foreign language curriculum for grades 1-4, the funding agency might ask to have grades 5 and 6 included. Such a request would probably add time and money to the original project plan and modify the schedule.

Finally there is the judgment of the project director as to the reasonable amount of time the activities in the project should consume. If the project director knows that certain persons or departments tend to make pessimistic time estimates, he may impose schedule requirements inconsistent with the estimates based on past experience and judgment.

Probability Aspects of PERT

One of the features of PERT which distinguishes it from other management systems is the use of probability theory as a predictive tool in forecasting the probable outcome of specific project plans. The theory is applied as outlined below.

Determine first the variance associated with each activity using the following formula

$$\sigma^2 = \left(\frac{b-a}{6}\right)^2$$

where b is the Pessimistic activity time estimate and a is the Optimistic time estimate.

Next find the standard deviation for any event in the network by tracing the longest path (in terms of time) through the network to the event in question by summing the activity variances on this path. The square root of this sum is extracted. The formula for finding event standard deviation is

$$\sigma_{T_{E_n}} = \sqrt{\sum_{i=0}^{n} \sigma_{t_{e_i}}^{2}}$$

using the standardized random variable "z" and normal probability tables. The formula is

$$z = \frac{T_S - T_E}{S_{T_E}}$$

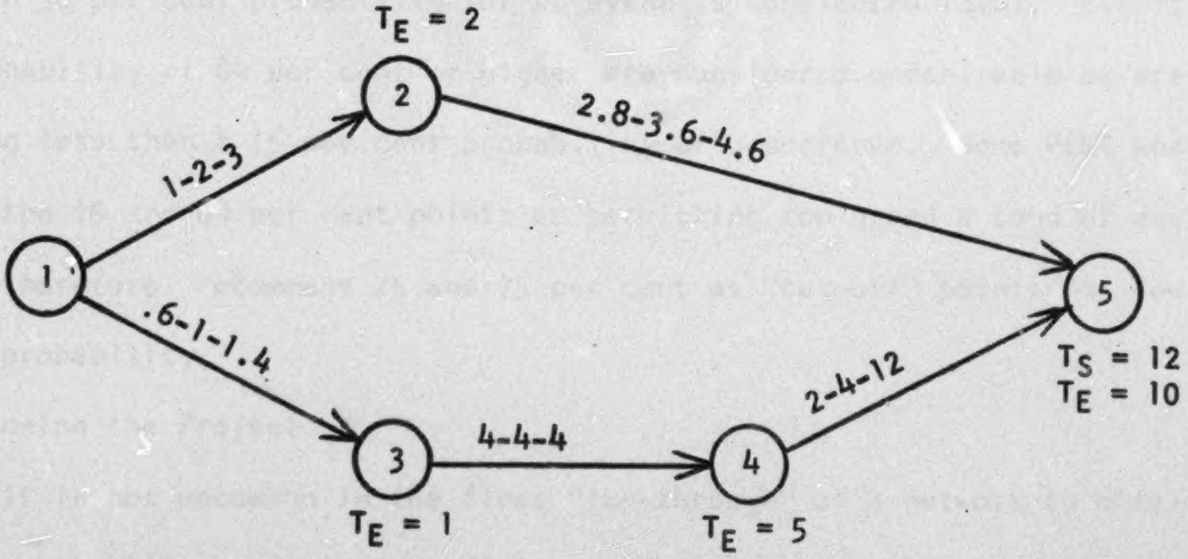
where T_S equals the scheduled date, T_E equals the Earliest Expected date, and S_{T_E} is the standard deviation for the event in question.

Figure 24 illustrates the determination of probability of meeting a scheduled date for the end event in a network, Event 5 in this example. The table under the network shows the following information from left to right: the activity, the Optimistic time, the Pessimistic time, the activity standard deviation, the activity variance, the event number, and the event standard deviation. The scheduled date for Event 5 is 12 weeks while the T_E for this same event is 10 weeks.

Insert Figure 24 about here

The z value of 1.134 has a probability of .87 in a normal curve table. Thus, the probability of completing has been determined as 87 per cent.

Figure 24. Determining the Probability of Meeting a Scheduled Date


$T_E = 2$
2
1-2-3
2.8-3.6-4.6
1
5
.6-1-1.4
$T_S = 12$
$T_E = 10$
2-4-12
4-4-4
3
4
$T_E = 1$
$T_E = 5$

Activity	a	b	S. D.	Variance	Event	Event S. D.
1 - 2	1.0	3.0	0.34	.1156	1	.34
1 - 3	0.6	1.4	0.14	.0196	2	.368
2 - 5	2.8	4.6	0.3	.0900	3	.475
3 - 4	4.0	4.0	0.0	.0000	4	.475
4 - 5	2.0	12.0	1.7	2.8900	5	1.764

$$z = \frac{12-10}{1.764} = 1.134 = .87 \text{ Probability}$$

Although no firm ground rules have been established for interpreting probability data, the following guidelines are considered useful in interpreting PERT information.

A 50 per cent probability for an event is considered ideal. Events with a probability of 84 per cent or higher are considered undesirable as are events having less than a 15 per cent probability of occurrence. Some PERT analysts view the 15 and 84 per cent points as permitting too broad a bond of deviation and, therefore, recommend 25 and 75 per cent as "cut-off" points for low and high probability.

Replanning the Project

It is not uncommon in the first "run-through" of a network to obtain undesirable probability and slack conditions. This is generally caused by the desire to establish an "ideal" project plan. When the ideal plan is not practical in terms of funding limitations, certain generalized procedures have been established for replanning networks.

The several techniques useful in modifying project plans are as follows:

1. Removal of Planned Constraints - As was discussed previously, planned constraints are those activity/event relationships which have been established as desirable but not absolutely necessary program relationships. Many such constraints are normally established in the formulation of an ideal project plan. Removal of the least significant of these constraints is a most important first in replanning the project.
2. Parallel Activities - Activities that are in sequential or linear order can, with the introduction of some management risk, be conducted in parallel. The decision to parallel activities will depend largely upon the availability of required resources as well as the degree of risk that the project director considers acceptable.
3. Eliminate Activities - The project may contain activities whose accomplishment might be desirable but possibly more time consuming than the project can afford. If these activities are not essential to the successful completion of the project, they can be eliminated.
4. Reallocate Resources - The addition of resources (personnel, equipment, or material) to the activities along the critical path will usually result in a reduction of the activity times along this path. In this manner, significant negative slack may be removed from the program plan. In using this technique it must be determined that the time saving justifys the increased cost.

5. Redefining Activities - The original plan will often contain activity descriptions that represent gross amounts of work. Careful examination of these gross activities often reveals specific activities which can be assigned a shorter cumulative time estimate as compared to the original gross activity. Further definition can take place in terms of performance levels for an activity. For example, in the case of a statistical study a smaller sample than originally planned might be taken.

It is important to stress that activity time estimates must not be shortened or "crashed" arbitrarily to meet a scheduled or directed date. Such a procedure invalidates PERT as a useful management tool.

Introduction to PERT/COST

As mentioned in Chapter I, an integrated management system plans, assesses, and controls three dimensions of a program - time, cost, and performance. Up to the present, no satisfactory method has been developed which consistently integrates these three dimensions. Since the establishment of PERT, a common base for the integration becomes available. Once this was recognized, the cost dimensions of planning were rapidly introduced into the PERT system (NASA, 1962, Navy SPO, 1961, and USAF, 1964)(2,8,23). The next aspect of the evolutionary development of integrated management system, based upon PERT, will be the introduction of the performance dimension into the basic system.

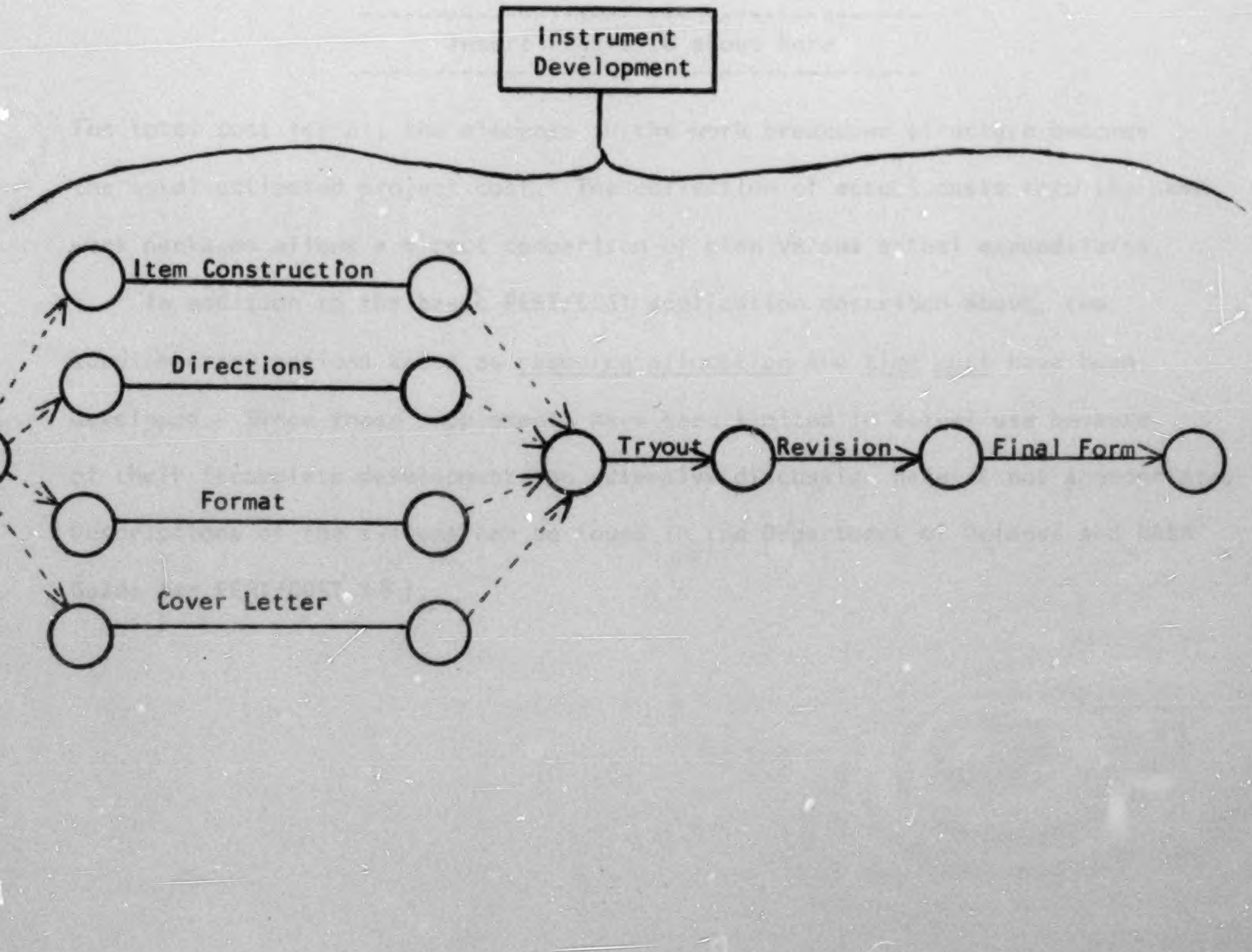
The principle objectives of the PERT/COST system are to aid in the development of a more realistic project estimate, to compare estimated and actual costs at any selected point in the program, to help determine the best allocation of resources to project activities, and to forecast the total project costs based upon program cost position throughout the project.

Cost estimates for a project should start when the work breakdown structure has been formulated and should be based upon the program elements and work packages depicted by the work breakdown structure. Although individual activities in a network may be cost estimated, this is considered a burdensome and time-consuming procedure for large networks.

Figure 24 presented earlier in the chapter illustrates the breakout of work involved in a survey project. The Instrument Development work package at Level 2 consists of the activities shown in Level 3. The relationship of the work package to the network is shown in Figure 25.

Insert Figure 25 about here

Figure 25. Relationship Between Work Package and Network Activities


Instrument Development
Item Construction
Directions
Format
Cover Letter
Tryout
Revision
Final Form

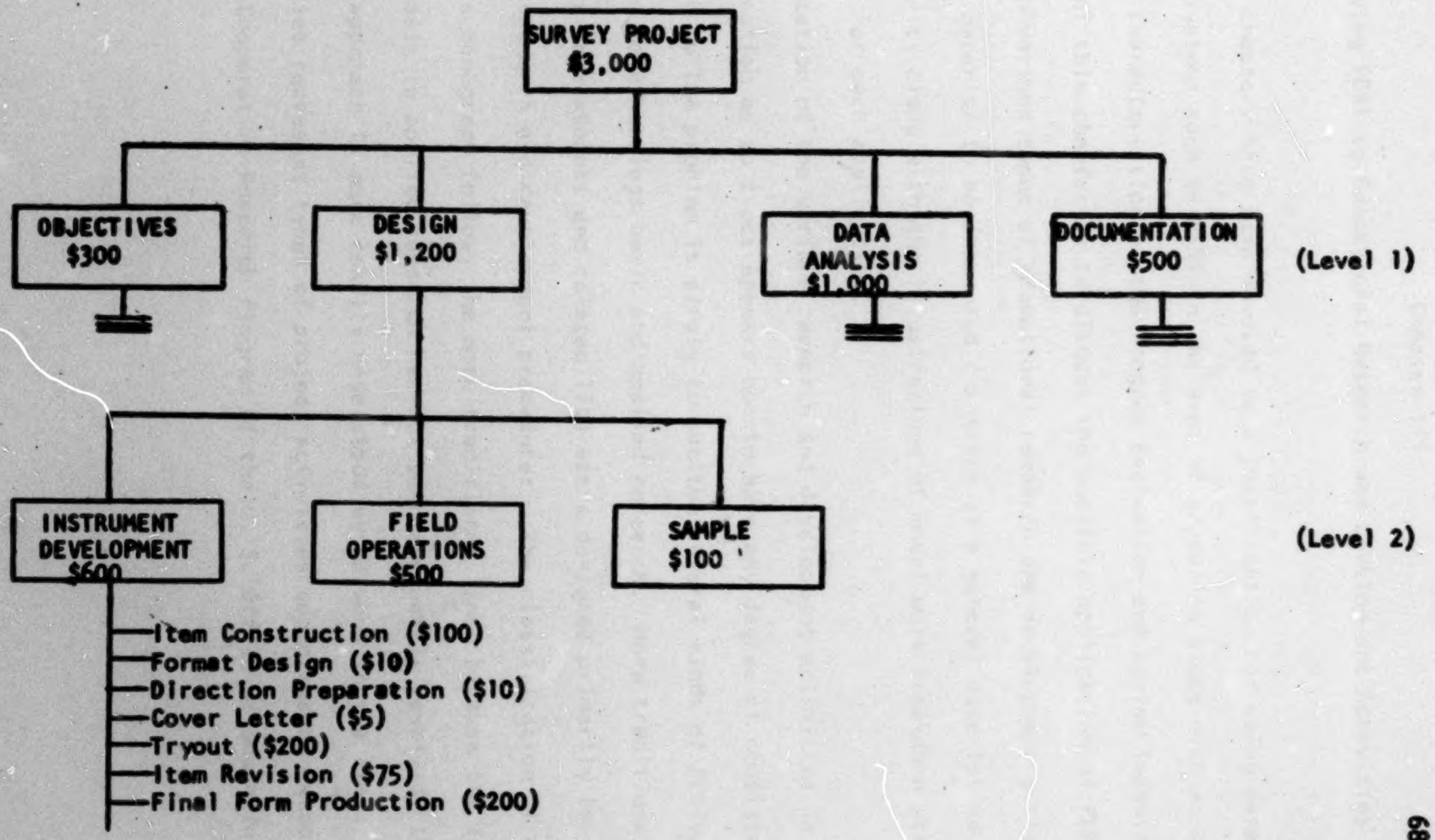
A cost estimate for the work package instrument development is based upon the resources (personnel, equipment, material, and direct and indirect cost) needed to do the tasks of the next tier done of the work breakdown structure. These tasks are shown as activities in the network in Figure 25. In order to find the total cost estimate for the project, the estimates are summed from bottom to top in the work breakdown structure. Figure 26 illustrates this procedure.

Insert Figure 26 about here

The total cost for all the elements in the work breakdown structure becomes the total estimated project cost. The collection of actual costs into the same work packages allows a direct comparison of plan versus actual expenditures.

In addition to the basic PERT/COST application described above, two supplementary options known as resource allocation and time cost have been developed. Since these supplements have been limited in actual use because of their incomplete development, an extensive discussion here is not appropriate. Descriptions of the systems can be found in the Department of Defense and NASA Guide for PERT/COST (8).

Figure 26. Summarization of Work Package Cost Estimates for Total Project Cost


SURVEY PROJECT $3,000
OBJECTIVES $300
DESIGN $1,200
DATA ANALYSIS $1,000
DOCUMENTATION $500
(Level 1)
INSTRUMENT DEVELOPMENT $600
FIELD OPERATIONS $500
SAMPLE $100
(Level 2)
Item Construction ($100)
Format Design ($10)
Direction Preparation ($10)
Cover Letter ($5)
Tryout ($200)
Item Revision ($75)
Final Form Production ($200)

Chapter III

Applying PERT to Educational Research and Development Activities

Introduction

Previous chapters have been devoted to a justification for using management information systems such as PERT in the area of education along with an outline of the basic characteristics of the Program Evaluation and Review Technique. The purpose of this chapter is to discuss the possible application of PERT techniques to various types of educational research and development activities. The specific material to be presented consists of a general description of each type of activity along with the illustrations of model work breakdown structures and networks for each application.

Categorization of the various research and development activities in the field of education as to types appears not to have any degree of consistency. One approach to the problem is simply to put the several kinds of activities under the two main headings basic and applied research. More traditional categories appear in textbooks and related literature designed primarily to train students in research and development procedures. The classification of activities for this monograph follows the more traditional lines because the issue of what is basic in applied research has not been adequately resolved, the traditional approach is more readily understood by persons in the field, and such activities represent types of project activities supported by agencies such as the Cooperative Research Program of the U. S. Office of Education.

The presentation of model work breakdown structures and networks for the various kinds of activities is presented with some reservation. The potential dangers in using model networks as a guide for PERT applications has been well documented by Miller (16). He points out that

> The objective of initial PERTing is to probe areas of uncertainty and discuss possible alternative paths before a final choice is made. The use of model networks at this point can be an aid; they may save time and provide more consistency in the overall network. However, . . . PERT is best applied to, and in fact was developed for non-standard situations and that model networks should, therefore, be used with great caution.[3]

Miller goes on to point out that the use of model networks may compromise one of the real objectives of PERT which is to obtain a network which is valid and meaningful to the person or persons who will actually be responsible for executing the work. It can be stated with some degree of assurance that in those areas for which PERT is used most effectively, no two programs are ever exactly identical nor will two individuals have exactly the same approach to the development of a network. Model networks therefore, should be used with caution. Project directors must always beware of the possibility of program modifications which will match the realities of their situation.

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[3] Miller, Robert W., Schedule, Cost, and Profit Control with PERT. McGraw Hill Book Company, New York, New York, 1963. P. 70.

The use of such models, however, can be of value to the person relatively inexperienced in PERT applications. The models developed and presented in this chapter, therefore, are presented only to serve as guides in the application of PERT to education and should not be considered as rigid suggestions.

Model PERT Applications

The development of models for any particular research or development activity is based on the presumption that there is sufficient experience with the activity so that the procedural steps involved have been identified and generally agreed upon. A careful review of the literature dealing with research methodologies reveals that for certain kinds of activities there is general agreement upon the procedural steps involved. On the other hand, certain kinds of research activities are relatively new and no systematic outline of procedures has yet been adequately developed which could serve as a model for other researchers to follow. For example, the procedural steps involved in organizing and conducting a survey research project have been pretty well established and are described in standard reference works. A person wanting to do such a project consults the reference in order to determine the work that has to be accomplished. The relative newness of developmental activities, however, mitigates against the development of a model since the activity has not been performed a sufficient number of times to establish the generalized procedure by which such activities are carried out. If a person wants to do a developmental type project, the standard reference works on research methodology do not provide any discussion or presentation of the steps involved. The types of research activities for which agreement exists upon procedural details include experimental research, survey research, historical research, curriculum research, and school plant and facility studies. Developmental projects, theory development projects, and projects concerned with integrating knowledge in a field have not been repeated in sufficient quantity to establish a generalized procedure which can be formulated to establish a model for others to follow. As such types of projects are conducted, a careful analysis of the work actually done can lead to the development of a general list of procedural steps. It is important to point out here that regardless of how well or ill-defined the procedural steps are, there can be deviations from the generalized model depending upon the purpose and scope of a research project involving any one or combination of methods employed.

The several models presented below were developed by consulting standard reference work on research methodology and from discussions with persons involved in the specific types of activities presented. Whenever possible the procedural steps were generalized and a model established. To those types of activities and projects where no generalized procedural outline was available, a model was developed using as a base an actual project which could be considered as representative of that particular type of activity. Each model presented below contains a descriptive categorical title, a brief explanation or definition of the type of work involved, and reference to an illustrative type of project. A model work breakdown structure is then presented in both tabular and graphical forms. A network follows reflecting the work described at the lowest level of the work breakdown structure. In developing the models, it was recognized that some of the activities might well be accomplished during a proposal preparation and hence, might be deleted from any operational work breakdown structure or network. It was decided to include such possible steps in order to provide for completeness of the model.

Experimental Research

This type of research is one of the most common type of activity carried out in the field of education. The general procedure is to manipulate selected variables, using experimental and control groups, in order to study the effect of such manipulation upon selected criterion variables. Such projects may be either short or long in duration but the steps involved are substantially the same. An example of experimentation would be an investigation designed to study the influence of vision training (corrective optical exercises) upon subsequent reading achievement.

The principal work components for this type of project along with the small work packages involved in each principal component are presented in tabular form in Figure 27 and graphically in Figure 28.

Insert Figure 27 and 28 about here

One additional level has been shown under the Measurements item at Level 2 in order to show how a further subdivision might be made to indicate the tasks to be done. A representative network for the project is presented in Figure 29. The network shows that the formulization of objectives and hypotheses precedes the development of the experimental design. In turn, once the design is developed

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Insert Figure 29 about here

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such activities as subject selection, procedural details and other activities can be accomplished, many in parallel. Once the treatments have been assigned and carried out, data collection and analysis can be made. The final set of activities consists of preparing a final report for the project.

Figure 27. Tabular Work Breakdown Structure for Experimental Project

LEVEL 0	LEVEL 1	LEVEL 2
Experimental Project	Problem Statement	Theoretical Framework Literature Review Objectives Hypotheses Generalization Considerations
	Design	Error Decision Treatments Definition Method of Analysis Work Guide Treatment Application Measurements
	Subjects	Sample Selection Treatment Assignment
	Analysis	Data Summary Statistical Tests Interpretation Conclusions
	Documentation	Narrative Tables Graphs Bibliography

Figure 28. Pictorial Work Breakdown Structure for Experimental Project

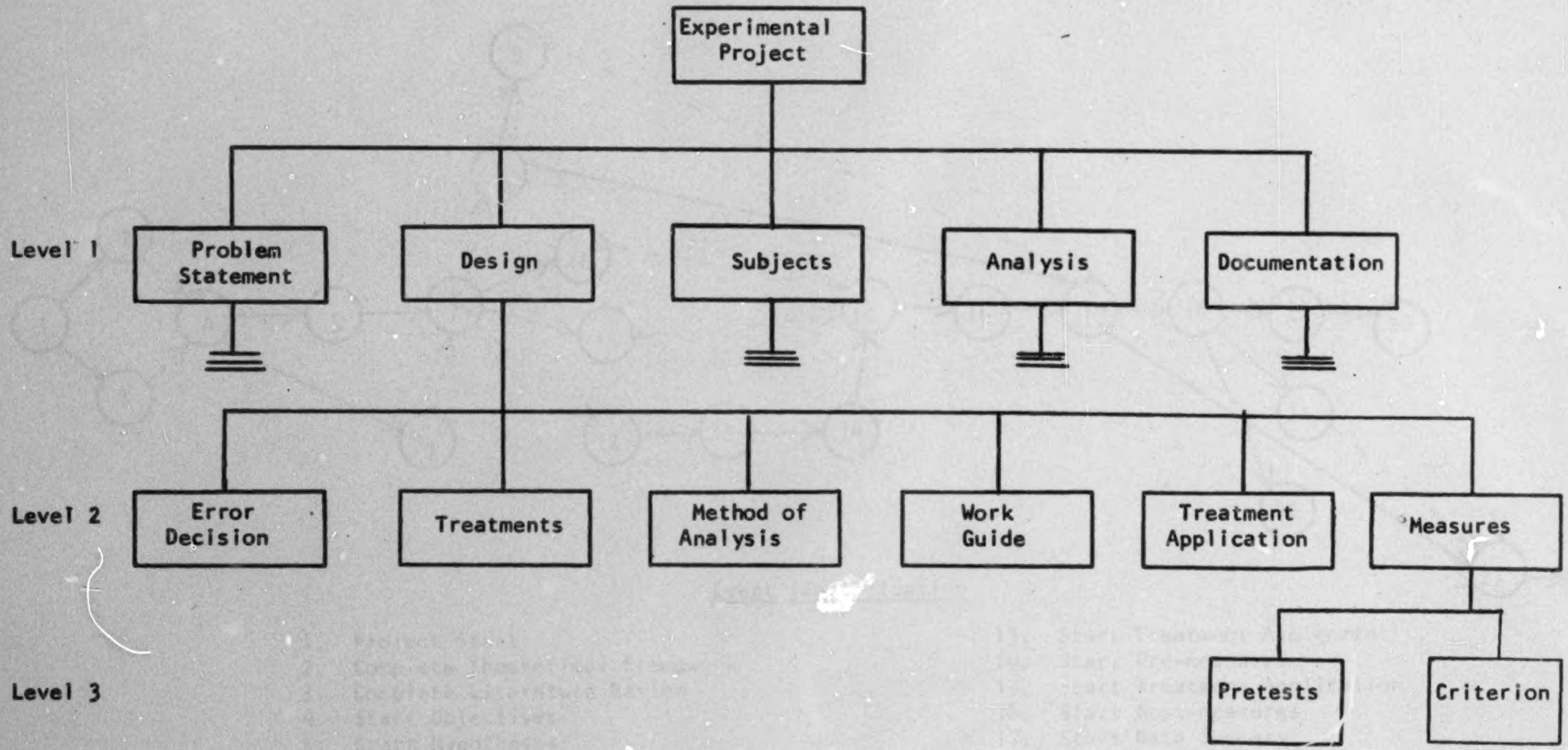
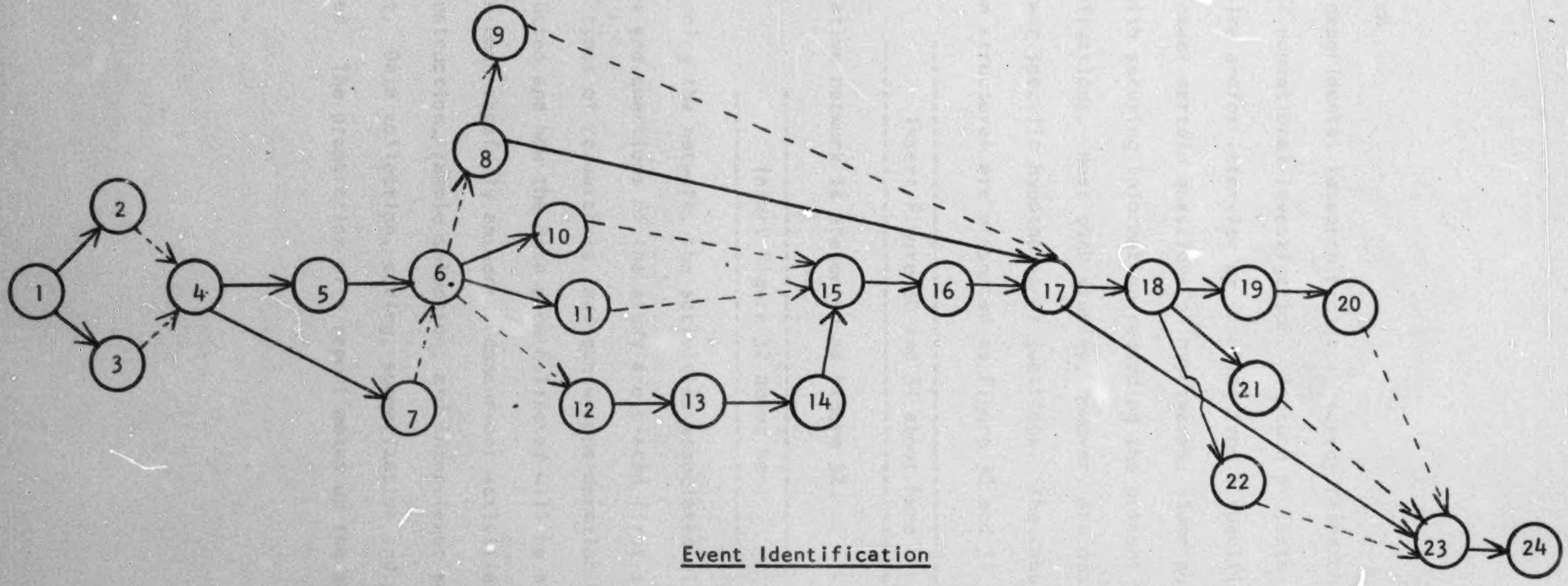

Experimental Project
Level 1
Problem Statement
Design
Subjects
Analysis
Documentation
Level 2
Error Decision
Treatments
Method of Analysis
Work Guide
Treatment Application
Measures
Level 3
Pretests
Criterion

Figure 29. Summary Network for Experimental Research Project



Event Identification

1. Project Start
2. Complete Theoretical Framework
3. Complete Literature Review
4. Start Objectives
5. Start Hypotheses
6. Complete Hypotheses
7. Complete Generalization Considerations
8. Start Method Analysis
9. Complete Decision Error
10. Complete Working Guide
11. Complete Treatment Definition
12. Start Sample Selection
13. Start Treatment Assignment
14. Start Pre-measures
15. Start Treatment Application
16. Start Post-measures
17. Start Data Summary
18. Complete Data Summary
19. Complete Interpretation
20. Complete Conclusions
21. Complete Tables
22. Complete Graphs
23. Complete Narrative
24. Complete Bibliography

Survey Research

Next to experimental research projects, survey research is probably the most common type of educational investigation. In such projects, data is collected by questionnaire and/or interview by sampling from a specified population universe in order to answer certain questions or hypotheses. Some survey research is concerned only with securing information regarding the present status of selected educational situations. Most such studies, however, are designed to secure information to answer specific hypotheses or questions. The tabular and pictorial work breakdown structures are presented as Figure 30 and 31 respectively.

Insert Figure 30 and 31 about here

The representative network is presented as Figure 32.

Insert Figure 32 about here

In developing the network, the activities associated with establishing the hypotheses and questions of the study are placed first since a most common fault of such types of research is inadequate consideration of why the study is being conducted and how the data once collected will be analyzed. Once these questions have been carefully answered, concurrent activities in the areas of instrument construction, sample selection, and interviewer selection can then be carried out. Data collection, coding, summarization and analysis can then be accomplished. The preparation of a report makes up the activities completing the project.

Figure 30. Tabular Work Breakdown Structure for Survey Research Project

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Survey Project	Problem Statement	Objectives Data Paradigms Hypotheses	
	Design	Sample	Universe Definition Sampling Plan Sample Selection
		Instrumentation	Item Construction Tryout Form Final Form
	Data	Collection	Administrative Procedures Interview Selection Schedule Establishment Field Interviews Follow-up
		Analysis	Coding Tabulation Statistical Tests Interpretation
	Documentation	Narrative Tables Charts	

Figure 31. Pictorial Work Breakdown Structure for Survey Research Project

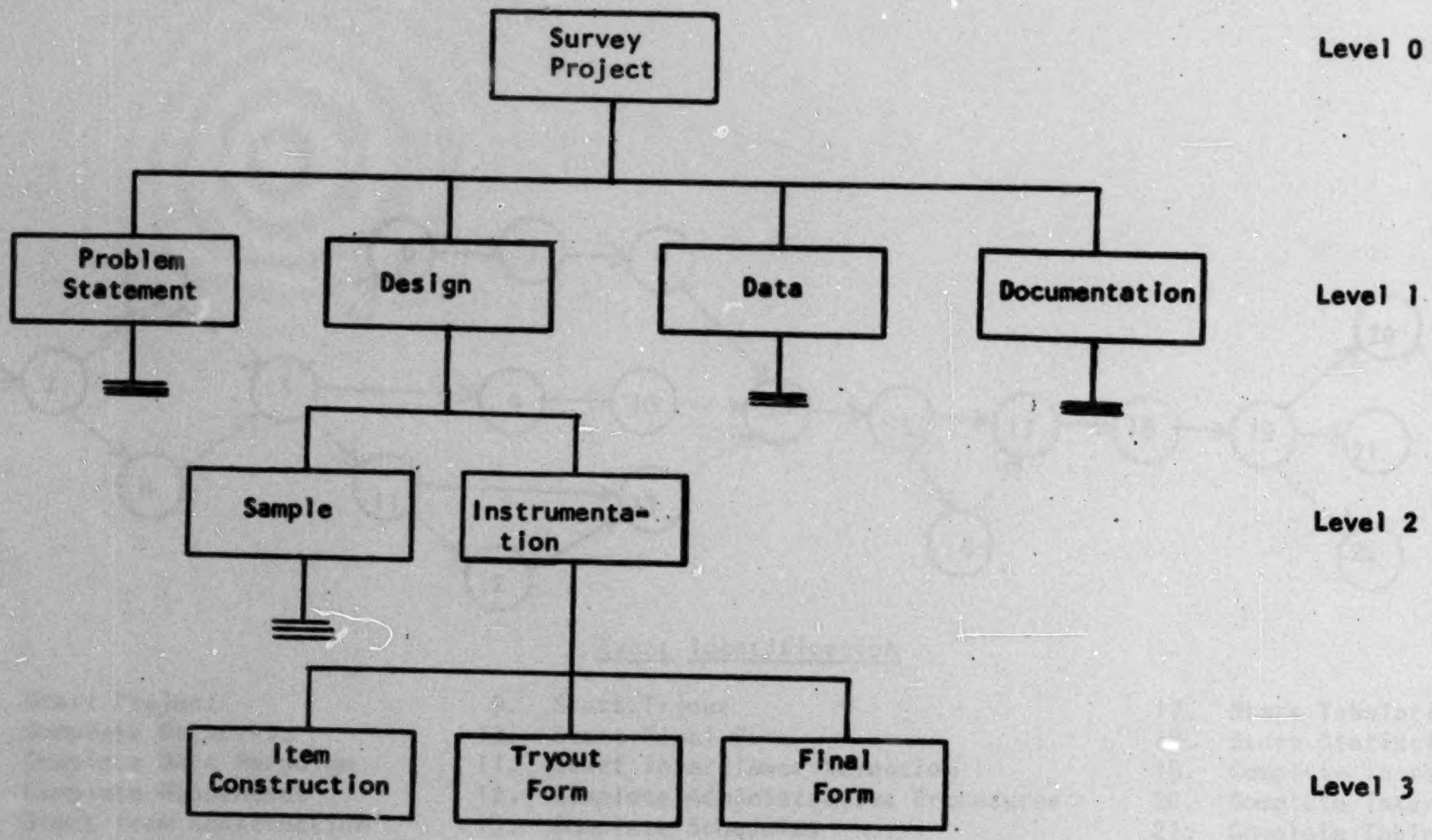
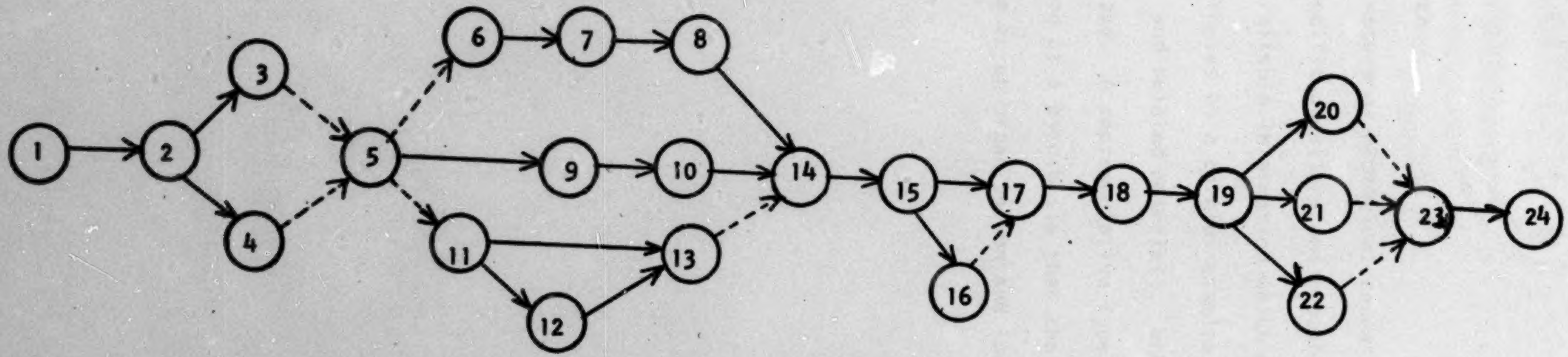

Survey Project
Level 0
Problem Statement
Design
Data
Documentation
Level 1
Sample
Instrumentation
Level 2
Item Construction
Tryout Form
Final Form
Level 3

Figure 32. Summary Network for Survey Research Project



Event Identification

1. Start Project
2. Complete Objective
3. Complete Data Paradigm
4. Complete Hypotheses
5. Start Item Construction
6. Start Universe Definition
7. Start Sampling
8. Start Sample Selection
9. Start Tryout
10. Start Final Form
11. Start Interviewer Selection
12. Complete Administrative Procedures
13. Complete Schedules
14. Start Field Interview
15. Start Data Coding
16. Complete Follow-up
17. Start Tabulation
18. Start Statistical Tests
19. Complete Tests
20. Complete Interpretation
21. Complete Tables
22. Complete Charts
23. Start Narrative
24. Complete Narrative

Historical Research

The general nature of historical research involves the use of existent data to answer specific questions and hypotheses. The researcher attempts to secure valid and reliable information which will lead to the acceptance or the rejection of hypotheses by a careful examination of historical records, contemporary documents, and related materials. Whenever possible, primary or original sources are utilized. A representative type of project would be one concerned with the validation of a hypothesis that the credit hour system has had strong positive influence on an organization and functions of universities.

The procedural steps involved in doing historical research have been generalized into three major steps: problem statement, data collection and interpretation, and documentation. The first and third activities exist in a much more definitive pattern than does the activity of data collection and interpretation. The procedure here consists of locating primary and secondary sources and concurrently applying the concepts of external criticism and internal criticism to the material. External criticism is concerned with determining the authenticity of the document or article while internal criticism is concerned with evaluating the accuracy and worth of the data in the document. One could conceive of these activities being carried out in a linear sequence as opposed to a parallel sequence. That is, one could locate source material, abstract it, and then apply criticism after all such material was located. On the other hand, persons involved in doing historical research usually state that the processes of locating sources and applying criticism are not mutually exculsive. Since new data is constantly coming to the attention of the investigator, historical research can be described as a continuous process. In the case of a funded project or one having some type of deadline imposed either by an investigator or external authority, the processes of locating and criticizing data sources must be terminated at some point in order to meet the schedule completion data. For this reason, an attempt was made to establish the flow of procedures involved in such a project.

A work breakdown structure for a historical research project in tabular form appears as Figure 33 with the same material being shown in pictorial form in Figure 34. Within the breakdown structure, an additional breakout of

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Insert Figure 33 and 34 about here

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work appears at Level 3 for the item in Level 2 referred to as Source Material and Evaluation. The reason for doing so is to indicate that the inspection and evaluation of sources probably can be best considered as a concurrent activity during the course of the project. The network for a representative type of historical project appears in Figure 35. In general, the network shows that the

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Insert Figure 35 about here

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initial activities consist of defining or delimiting the problem and establishing hypotheses, work involved in obtaining and evaluating source material, and summarizing the data, with the concluding set of activities involved in document preparation.

Figure 33. Tabular Work Breakdown Structure for Historical Research Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
Historical Research Project	Problem Statement	Delimitation Questions and Hypotheses	
	Data Collection	Procedures	Note Taking System Abstract Procedures Document Sources
		Source Material and Evaluation	Primary Sources Secondary Sources External Criticism Internal Criticism
		Data Summary	Interpretation Conclusions
	Documentation	Narrative Bibliography	

Figure 34. Pictorial Work Breakdown Structure for Historical Research Project

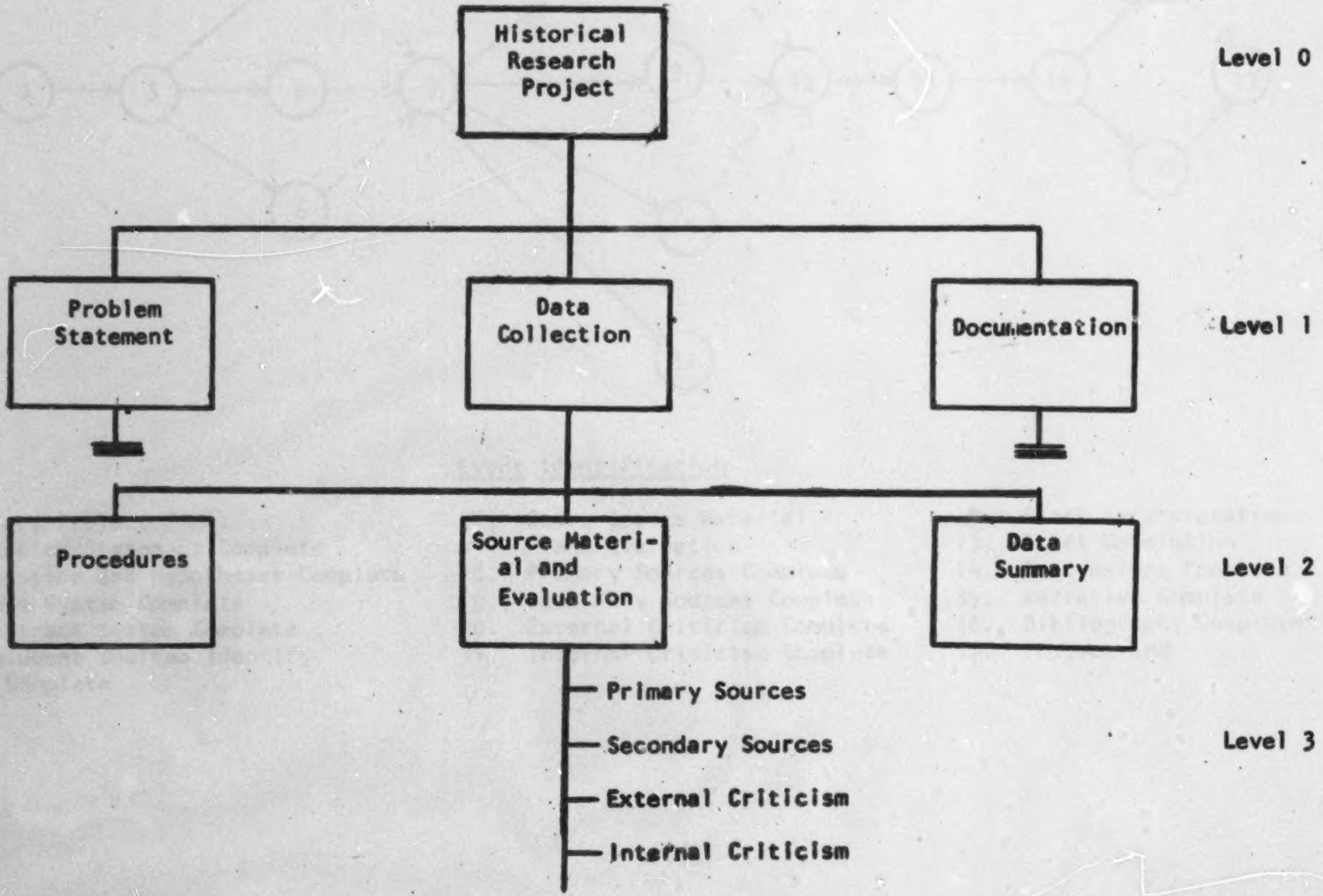
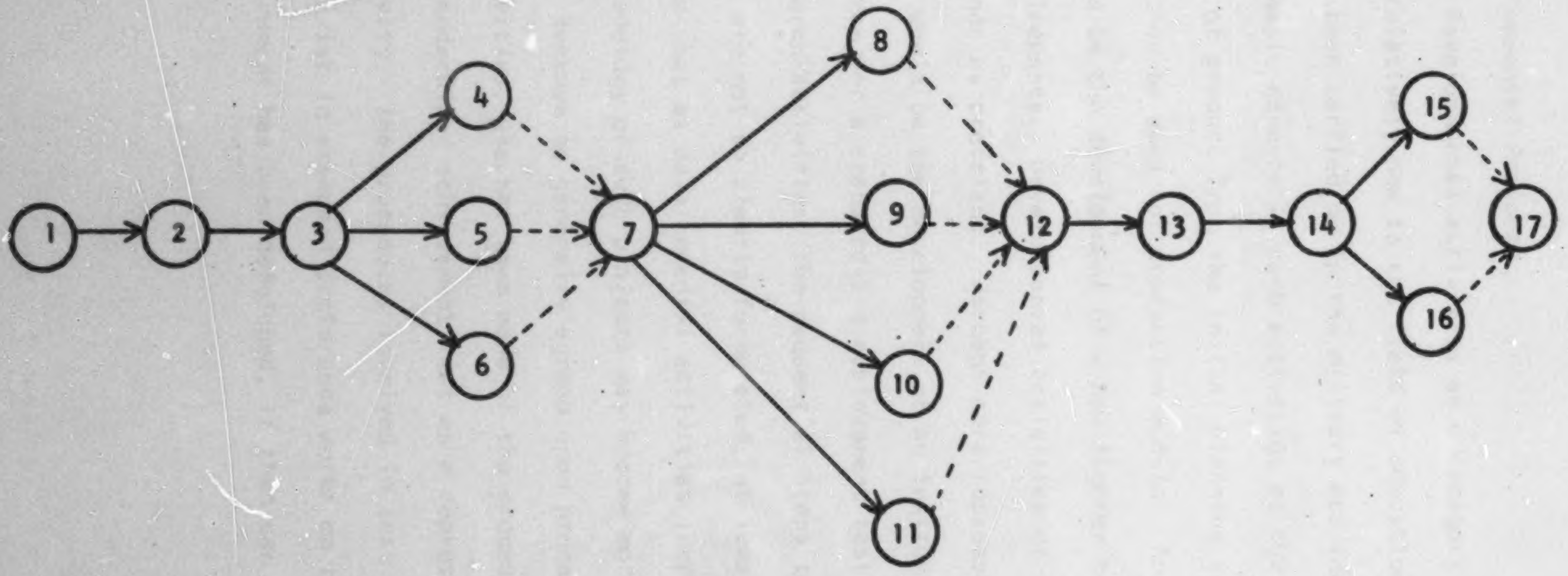

Historical Research Project
Level 0
Problem Statement
Data Collection
Documentation
Level 1
Procedures
Source Material and Evaluation
Data Summary
Level 2
Primary Sources
Secondary Sources
External Criticism
Internal Criticism
Level 3

Figure 35. Summary Network for Historical Research Project



Event Identification

1. Start Project
2. Problem Statement Complete
3. Question and Hypotheses Complete
4. Note System Complete
5. Abstract System Complete
6. Document Sources Identify Complete
7. Start Source Material and Evaluation
8. Primary Sources Complete
9. Secondary Sources Complete
10. External Criticism Complete
11. Internal Criticism Complete
12. Start Interpretation
13. Start Cohelusion
14. Conclusions Complete
15. Narrative Complete
16. Bibliography Complete
17. Project End

Developmental Projects

Developmental activities as a category of research and development programs are relatively new to the field of education although such types of activities have been carried on in the military and industrial situations for many years. The basic concern is such activities as the production of a particular kind or type of product from the initial planning stages through to prototype items which can then be used for production models. An illustrative case in the military would be the development of a new fighter bomber designed to meet certain specified requirements. Developmental activities of this type in the field of education are not as prevalent. Perhaps more representative types of activities in education would be the development of an instructional motion picture, a television program, or a standardized achievement test. In contrast to other types of research activities, the sequential steps to be followed in a developmental project are not so clearly formulated, at least at the present time. It is anticipated that as developmental activities increase in the field of education, the methodology of such projects may become more firmly established.

Because no generally agreed upon procedure exists for developmental activities, use has been made of the processes involved in the development of a standardized achievement test as a representative type of developmental activity. The procedures involved in test development are pretty well established and exist in standard preference works on test construction (11). Once the instrument has been developed, it then can become a production-type item.

The general end item test development consists of a test booklet and accessory material. Activities associated with the booklet consist of preparing a test plan which includes the purpose and nature of the test, item construction and tryout, final form preparation, and normative data. Accessory materials to accompany the test booklet consist of answer sheets, administrative directions, and similar items. The test booklet and accessory material preparation comprise Level 1 of the tabular work breakdown structure shown in Figure 36. The major

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Insert Figure 36 about here

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end item of a test booklet is further broken down into the preparation of a test plan, the creation of an item pool, plus the development of tryout and final forms of the test. The accessory materials consist of the manual containing pertinent test information, the answer sheets to be used, along with the scoring procedure. Succeeding levels of the work breakdown structure show further detail work under each of the Level 3 sub-divisions. A pictorial presentation of the work breakdown structure occurs in Figure 37.

Insert Figure 37 about here

The network for a test development project following the above work breakdown structure is presented as Figure 38.

Insert Figure 38 about here

Figure 36. Tabular Work Breakdown Structure for Achievement Test Development Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Achievement Test	Test Booklet	Test Plan	Purpose Objectives Content Specifications	
		Item Pool	Item Writers	
			Test Items	Item Drafts Item Review
		Test Forms	Tryout Forms	Student Directions Administration Directions Tryout Sample Form Assembly Tryout Administration Statistical Analysis Revised Item
			Final Form	Student Directions Administration Directions Norm Sample Final Test Booklet Norm Administration Statistical Analysis Normative Data
	Accessory Material	Manual	Outline Preliminary Draft Final Draft	
		Answer Sheets	Machine-Score Hand-Score	
		Scoring Procedure	Keys Directions	

Figure 37. Pictorial Work Breakdown Structure for Achievement Test Development Project

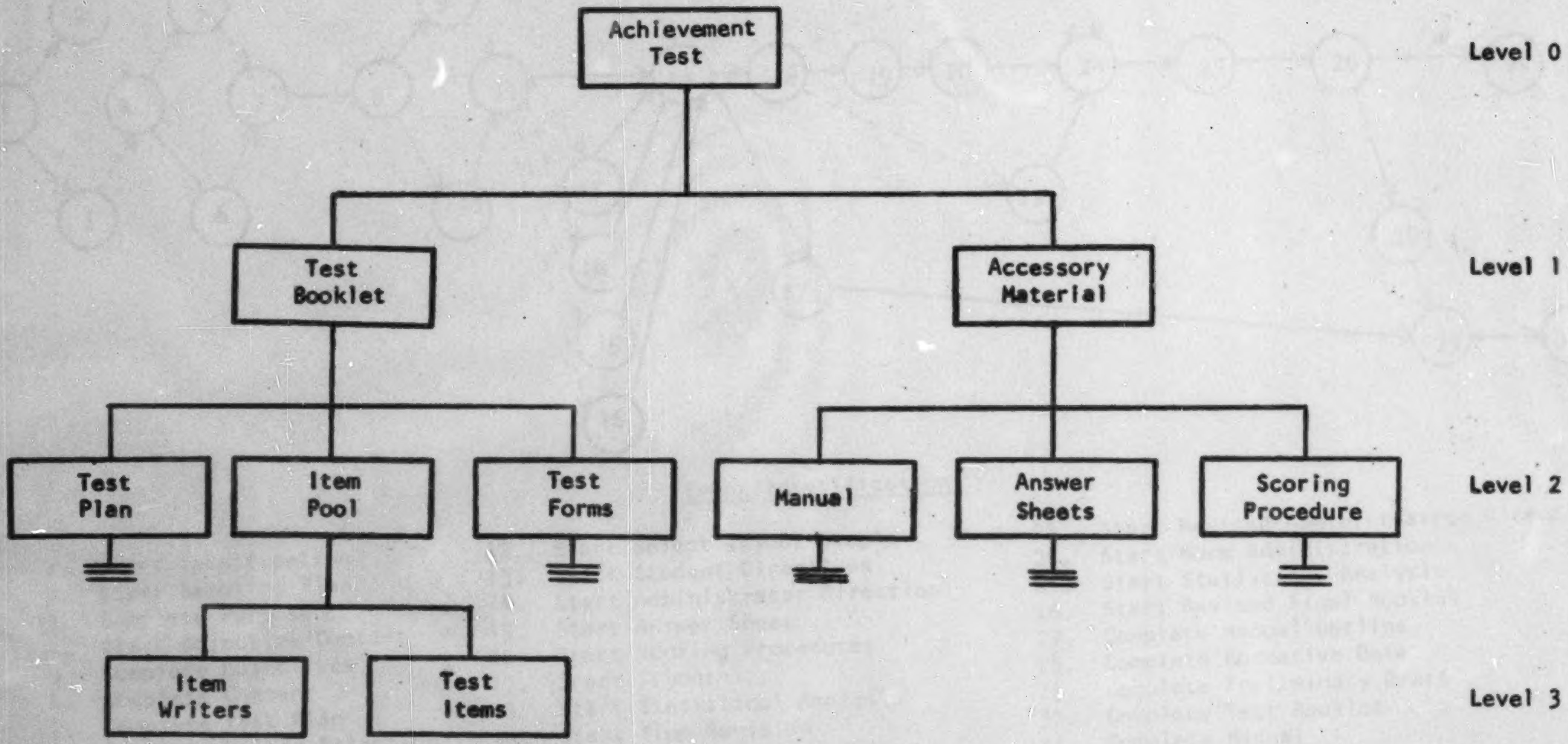
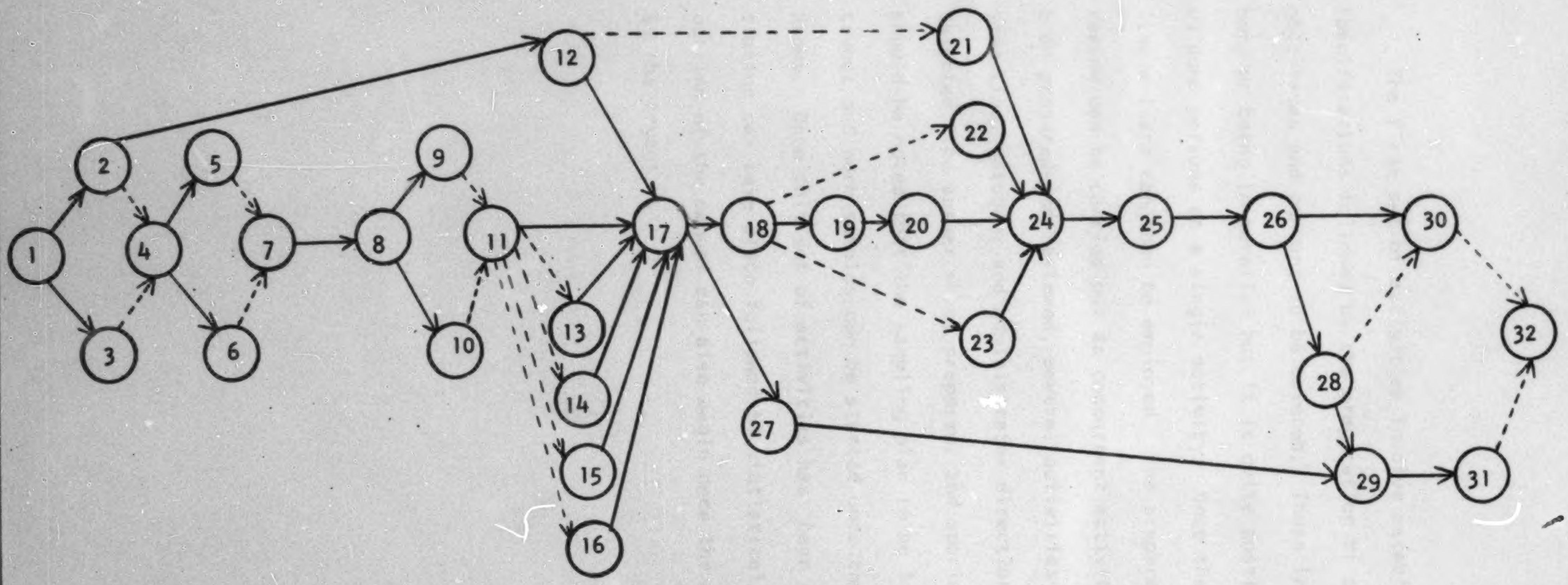

Achievement Test
Level 0
Test Booklet
Accessory Material
Level 1
Test Plan
Item Pool
Test Forms
Manual
Answer Sheets
Scoring Procedure
Level 2
Item Writers
Test Items
Level 3

Figure 38. Summary Network for Achievement Test Development Project



Event Identification

1. Start Specification
2. Start Sampling Plan
3. Complete Purpose
4. Start Objective/Content
5. Complete Objectives
6. Complete Content
7. Complete Test Plan
8. Complete Writer Selection
9. Complete Item Drafts
10. Complete Item Review
11. Start Form Assembly
12. Start Select Tryout Sample
13. Start Student Directions
14. Start Administrator Directions
15. Start Answer Sheet
16. Start Scoring Procedures
17. Start Tryout
18. Start Statistical Analysis
19. Start Item Revision
20. Start Final Test Booklet
21. Start Norm Sample
22. Start Revised Student Directions
23. Start Revised Administration Directions
24. Start Norm Administration
25. Start Statistical Analysis
26. Start Revised Final Booklet
27. Complete Manual Outline
28. Complete Normative Data
29. Complete Preliminary Draft
30. Complete Test Booklet
31. Complete Manual
32. Project Complete

The first set of activities involve establishing the test's purpose and specifications followed by the preparation of an outline showing the subject, objectives and content to be covered. These latter two activities are shown here as being in parallel but it is quite possible that they might be considered by some persons as a single activity. Once the test plan has been prepared, item writers can then be employed. The preparation of item drafts and their review can be carried out as concurrent activities. Once the item drafts have been prepared and reviewed, several activities can then be carried on at the same time. Student and administrator directions can be prepared, the tryout sample selected, the answer sheet prepared, and scoring procedures established. It should be noted that the sampling plan to be followed in selecting both the tryout and norm samples can be started once the specifications for the test are known. Once this set of activities has been accomplished, the tryout administration can take place followed by statistical analysis and item revision. An outline of the manual can also begin once the materials have been assembled by the tryout.

Upon completion of the item revision, the final form of the test is assembled. Experience gained in the tryout administration can be used to revise student and administrator directions. The final norming sample is selected following the sampling plan established by the tryout sample. Upon accomplishment of these activities, the normative administration can then be made which is followed by a statistical analysis of the test data and the establishment of the desired normative data. While the above activities are being carried out, a preliminary draft of the manual may be prepared but the final form cannot be accomplished until normative data are available from the final test administration. The project can be considered finished when both the test booklet and manual are considered as complete.

Curriculum Development

The development of curricula and accompanying instructional materials is a continuous process in the field of education. Consequently, the steps involved in developing a new curriculum unit or revising an existing one have been fairly well established. Curriculum development can take place as a joint teacher-student activity in a particular subject area during the course of a semester or it can take the form of a resource unit made available to teachers as needed. A curriculum can be developed on a national scale as witnessed by the projects such as the SMSG Mathematics Program, the Physical Science Study Committee, Project English, and similar programs. On the other hand, local school districts often undertake their own curriculum development activities.

The principal goal of a curriculum development project is to provide the teacher with a rather complete package of instructional materials, including an orientation to their development and use. Thus, it is possible to say that two major work activities constitute the production of a curriculum. One major activity is concerned with the development and preparation of instructional materials while the other is concerned with the process of disseminating information about the materials.

The preparation of instructional materials consists of work centering around determining the instructional goals and evaluating them from several points of view plus establishing the structure to be used in organizing the knowledge in the subject field. Once the objectives and structure have been determined, initial material development can begin. Identifiable work units center on the teacher material, the student material, audio-visual materials, evaluation techniques, and additional reference material. After the initial materials have been developed, they are then subjected to a field test or tryout with a selected sample of schools. Upon completion of the tryout and evaluation of materials, the final instructional material can then be prepared.

The dissemination process can begin early in the project by outlining the necessary procedure and selection of the schools before all of the material is ready. When the final materials are available, teachers and administrators can then be oriented to their nature and use. Lay personnel in the forms of PTA groups can then be oriented once the school staff understands the material.

The tabular work breakdown structure appearing in Figure 39 identifies the work units within the two major work areas. The pictorial illustration of the work breakdown appearing in Figure 40 shows only the work units making up the work area labeled Initial Materials. The network for a curriculum project shown in Figure 41 indicates that determination of objectives and structure could be considered as occurring concurrently and some aspects of the dissemination process being initiated upon the start of the project. Once the goals and structure have been established, the material is then prepared. Upon completion of the field test, final materials are then shown as being developed, In turn, the preparation of publications, reports, and manuals is shown to constrain the orientation of teachers, administrators, and lay personnel. It might be desirable to include some further activities associated with feedback obtained from dissemination-orientation phase if so desired.

Insert Figure 39 and 40 about here

Insert Figure 41 about here

Figure 39. Tabular Work Breakdown Structure for Curriculum Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Resource Unit	Material Preparation	Objectives	Goals	Philosophical Evaluation Psychological Evaluation Content Evaluation Measurement Evaluation
			Structure	Determination Evaluation
		Instructional Materials	Initial Material	Teacher Material Student Material A-V Aids Evaluation Techniques Reference Material
			Field Test	Procedures School Sample *Material Distribution* Tryout Evaluation
			Final Material	Revised Teacher Material Revised Student Material
	Dissemination	Publication	Texts Manuals Reports	
		Orientation	Teachers Administrators Lay Personnel	

Figure 40. Pictorial Work Breakdown Structure for Curriculum Project

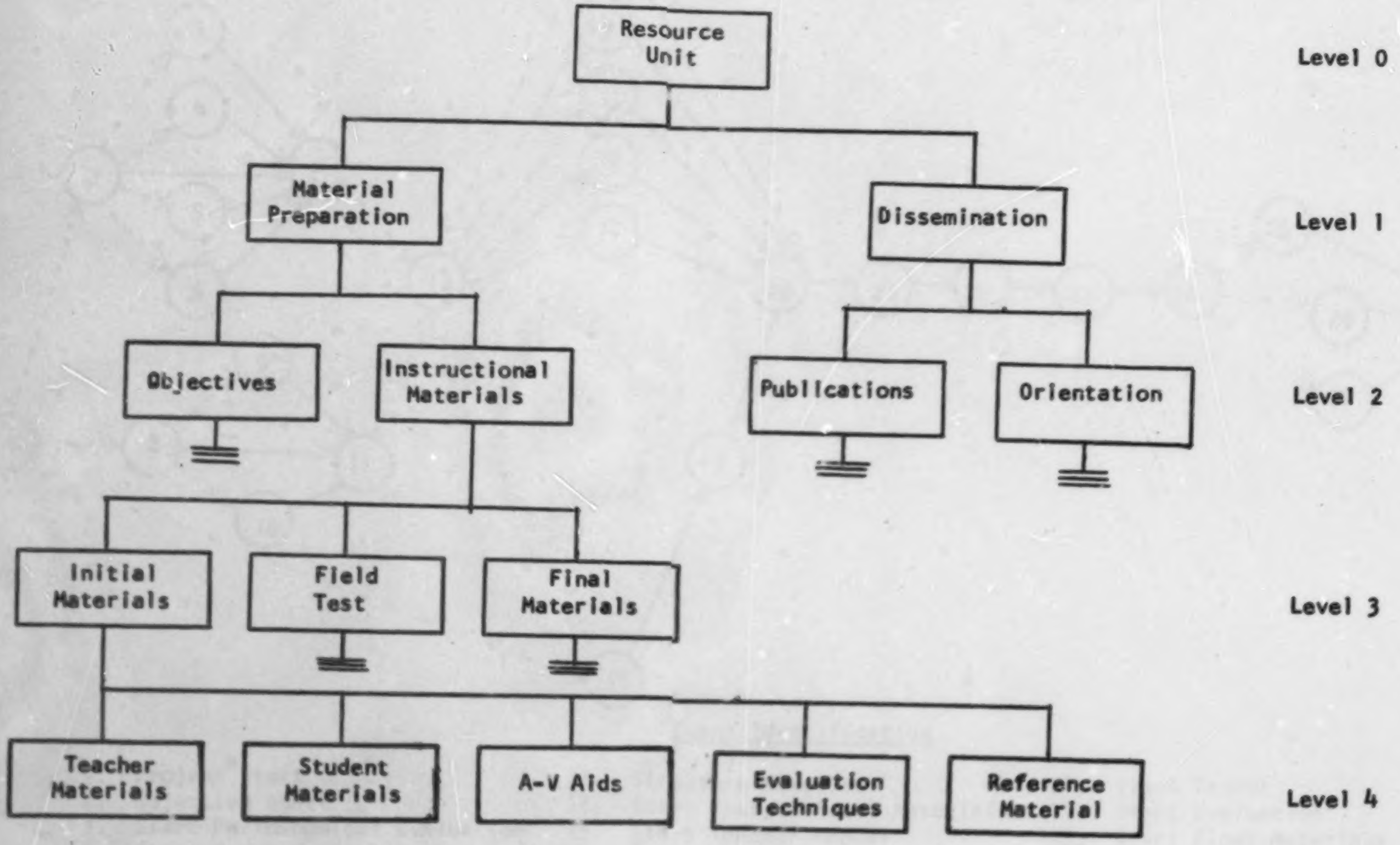
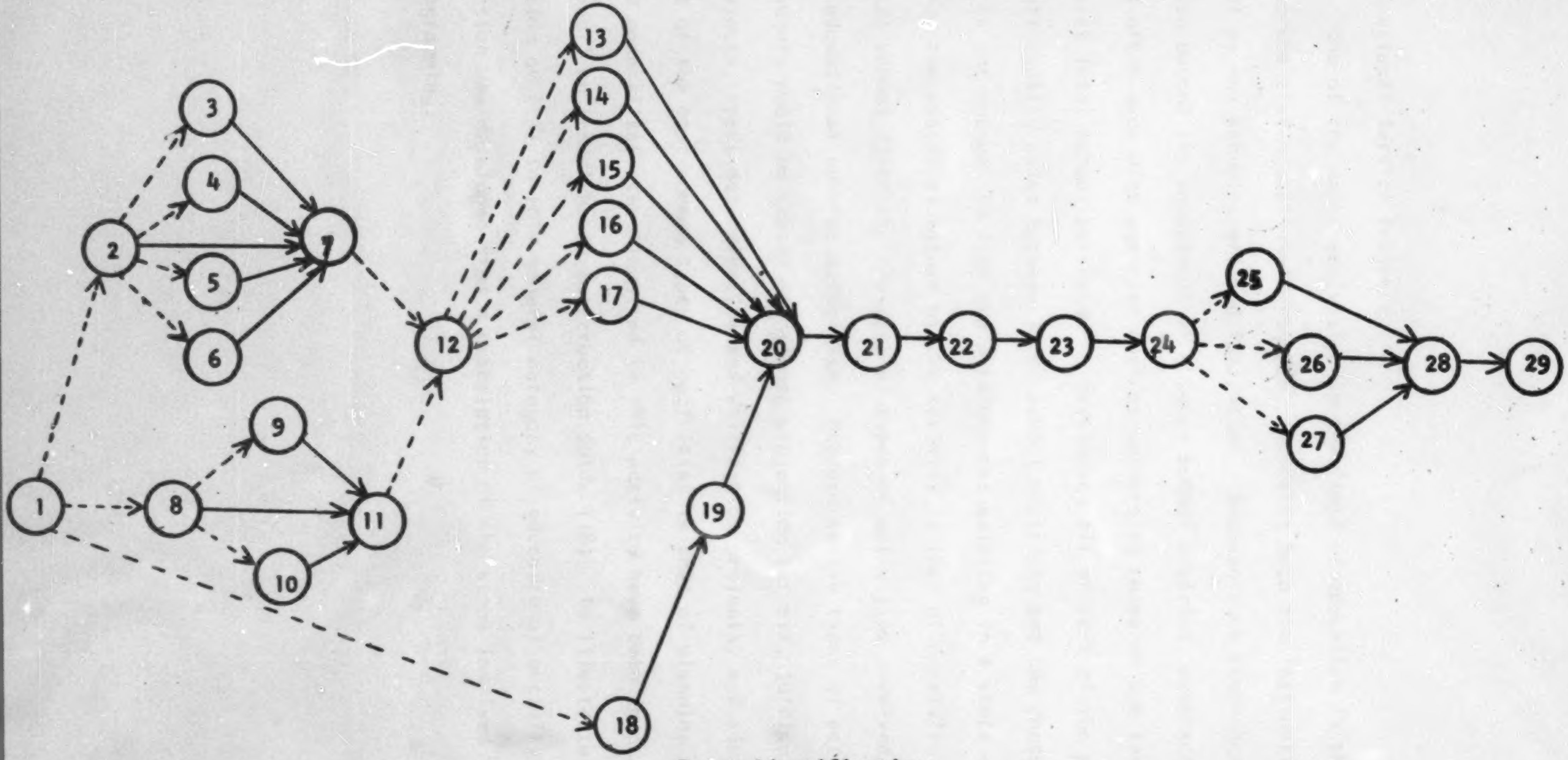

Resource Unit
Level 0
Material Preparation
Dissemination
Level 1
Objectives
Instructional Materials
Publications
Orientation
Level 2
Initial Materials
Field Test
Final Materials
Level 3
Teacher Materials
Student Materials
A-V Aids
Evaluation Techniques
Reference Material
Level 4

Figure 41. Summary Network for Curriculum Project



Event Identification

1. Project Start
2. Objective Start
3. Start Philosophical Evaluation
4. Start Psychological Evaluation
5. Start Content Evaluation
6. Start Measurement Evaluation
7. Objectives Complete
8. Start Structure
9. Start Determination
10. Start Evaluation
11. Structure Complete
12. Start Instructional Materials
13. Start Teacher Manual
14. Start Student Material
15. Start A-V Aids
16. Start Evaluation
17. Start Reference
18. Start Dissemination Procedure
19. Start School Sample
20. Start Material Distribution
21. Start Tryout
22. Start Evaluation
23. Start Final Materials
24. Complete Final Materials
25. Start Publications
26. Start Teacher Orientation
27. Start Administration Orientation
28. Start Lay Orientation
29. Project Complete

Educational Service Projects

One of the major activities in the field of education is that of planning comprehensive educational programs, including both the instructional program as well as the school plant and facilities. Because such comprehensive planning is often beyond the competency of a local school district, contractual arrangements are often made with agencies such as university research and service bureaus to assist local school personnel in developing all or part of the plan. Such arrangements usually exist between local school districts and the consulting agency but it is not unusual to find the arrangements existing in a state or regional basis. Since the essential nature of the activity is that of providing a service to the local school district, the general types of activities involved have been categorized as educational service activities. Representative types of activities in this category would be school enrollment projection surveys, curriculum evaluation projects, space determination and utilization projects, and similar activities. One of the most common types of activities is that of planning the school plant. The generalized steps involved in this activity have been described in the National Council on School House Construction Guide (18). To illustrate the possible application of PERT to this general category of educational activity, the model in this section was developed from a description of the steps involved in school plant programming.

Activities associated with school plant can be sub-divided into four major work areas as shown in Figures 42 and 43. First, a district-wide plant survey

Insert Figures 42 and 43 about here

is made in order to develop a master plan for future school district construction. This activity is followed by establishing specifications for buildings within the district. The specifications then serve as a guide for the architectural planning, design, and construction of buildings. The provision of equipment and the actual occupation of the new building complete the activities. Detailed descriptions of each of these steps is provided in the above reference.

The model work breakdown structures presented in this section, therefore, should probably be considered as representing major work units. The network shown in Figure 44 presents only the major activities to be done and thus, should be considered as a summary rather than a detailed network for this type of project. Detailed networks could be established to show the plan for the actual work involved in the construction phase or any other aspect of the plan where management control is essential.

Insert Figure 44 about here

Figure 42. Tabular Work Breakdown Structure for School Plant Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
School Plant Program	District-Wide Plant Survey	Determination of Present and Future Needs	Enrollment Projections Educational Program Projections Summary of Needs
		Existing Resource Survey	Current Plant Appraisal Finance and Planning Report
		Recommended Plan	Long Range Plans Short Range Plans Immediate Plans
	Educational Building Specifications	Educational Program Planning Review	
		Teaching-Station and Space Requirements	
		Specifications Guide	Quantitative Dimensions Qualitative Dimensions
		Review Architectural Plan	
	Architectural Plans and Construction	Architect Employment	Selection Services
		Construction	
	Employment and Occupancy	Furniture and Equipment Selection	
		Teacher-Student Orientation	
		Document File	
		Public Relations	

Figure 43. Pictorial Work Breakdown Structure for School Plant Project

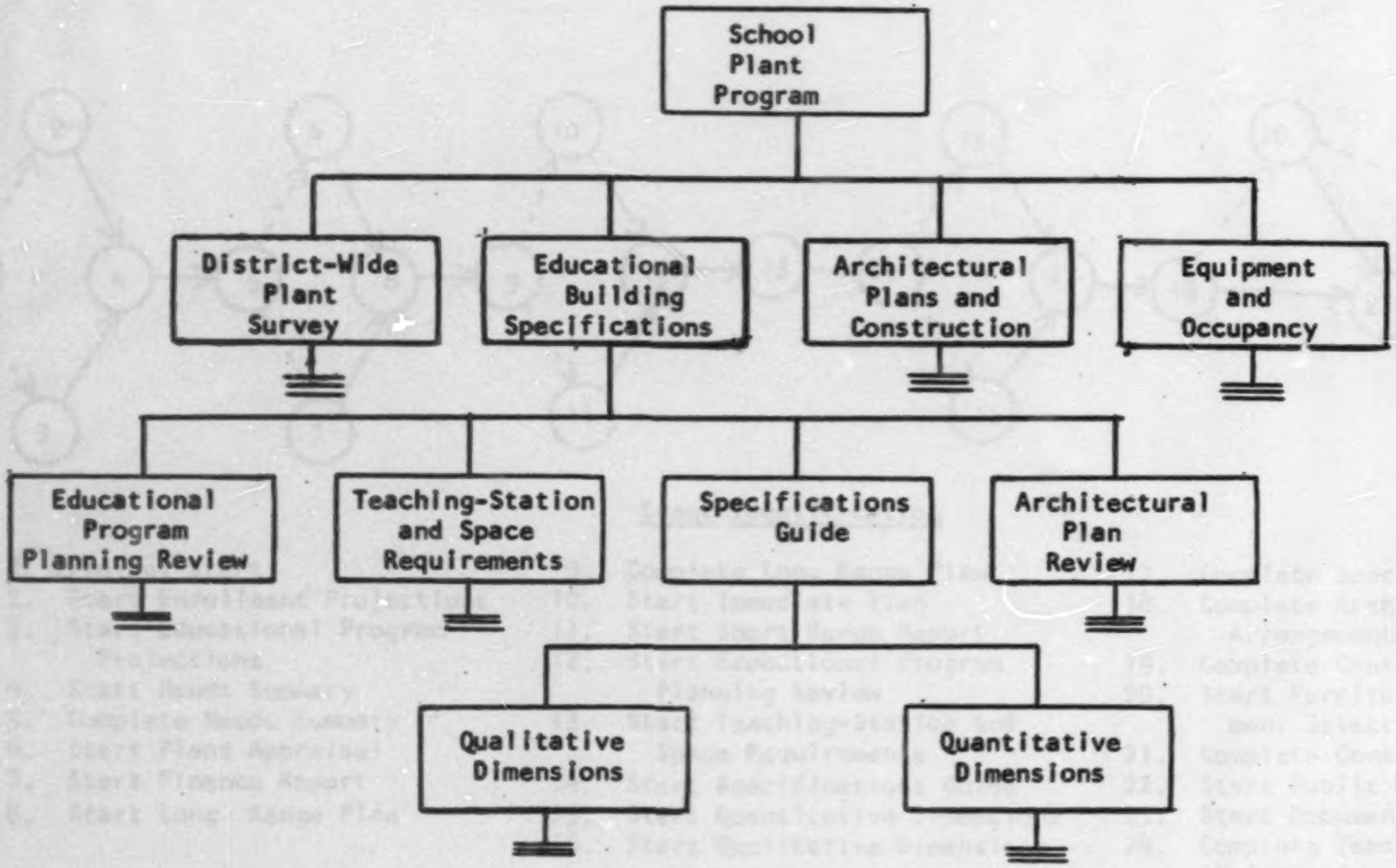
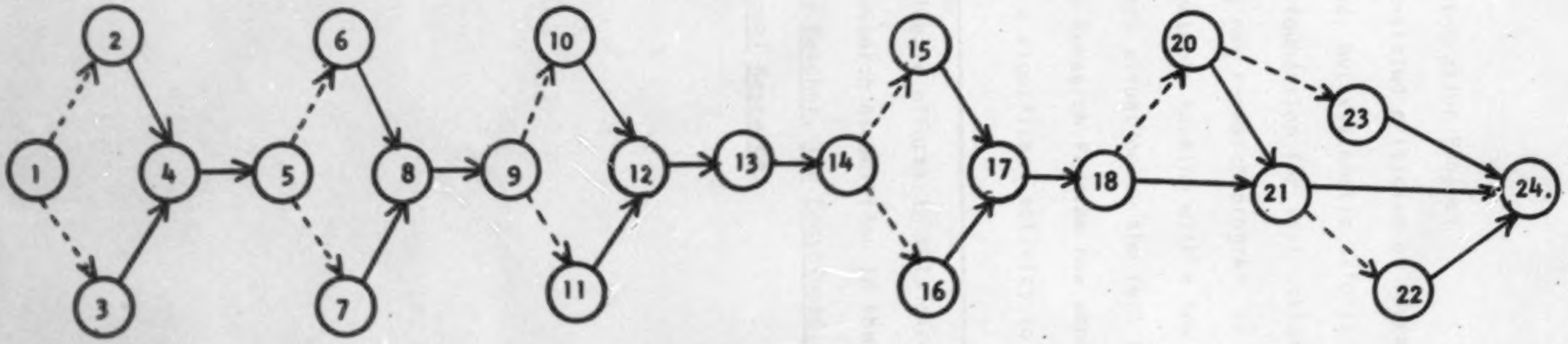

School Plant Program
District-Wide Plant Survey
Educational Building Specifications
Architectural Plans and Construction
Equipment and Occupancy
Educational Program Planning Review
Teaching-Station and Space Requirements
Specifications Guide
Architectural Plan Review
Qualitative Dimensions
Quantitative Dimensions

Figure 44. Summary Network for School Plant Project



Event Identification

1. Project Start
2. Start Enrollment Projections
3. Start Educational Program Projections
4. Start Needs Summary
5. Complete Needs Summary
6. Start Plant Appraisal
7. Start Finance Report
8. Start Long Range Plan
9. Complete Long Range Plan
10. Start Immediate Plan
11. Start Short Range Report
12. Start Educational Program Planning Review
13. Start Teaching-Station and Space Requirements
14. Start Specifications Guide
15. Start Quantitative Dimensions
16. Start Qualitative Dimensions
17. Complete Specification Guide
18. Complete Architectural Arrangements
19. Complete Construction
20. Start Furniture and Equipment Selection
21. Complete Construction
22. Start Public Relations
23. Start Document File
24. Complete Teacher-Student Orientation

Research Integration Project

An oft-stated criticism of educational research is that much work has been accomplished, but systematic efforts to integrate the research so that it can serve as a foundation for instructional procedures and/or as a guideline for undertaking new research programs to cover areas not adequately investigated have been notably lacking with a few exceptions.[4] Recent recognition has been given to this situation by the fact that the United States Office of Education Cooperative Research Program now considers the conduct of research integration studies as a significant activity to be given funded support.

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[4] Valuable efforts in this direction have been made by The American Educational Research Association in their publications of the series on What Research Says to the Teacher, The Encyclopedia of Educational Research, and The Review of Educational Research.

This type of project involves a systematic review of unpublished and published research in a defined area of education for the purpose of establishing a set of educational principles, to develop a theory which can then be used as a guide to the establishment of current educational practices, or to determine the present state of research. An example of such a project would be a systematic review of research literature relating to the field of music education conducted at The Ohio State University under a grant from The Cooperative Research Program (21). The particular goal of this project is not to establish a list of instructional principles or music education but to establish the areas in music education which have been researched and those which need yet to be researched. The outline presented below represents a generalized model for this type of research derived largely from the experience gained in conducting such an activity by the personnel engaged in the music education research synthesis project. It is important, therefore, to recognize that a project similar in nature might deviate from the model in some of the tasks to be done.

The general work to be done in such a project is to establish a procedure for evaluating the research, followed by activities associated with collecting the data (in this case research documents), developing a system for classifying the research, and then conducting an integration and synthesis of research findings.

A tabular work breakdown structure for such a project is presented in Figure 45 with a pictorial illustration of the same work breakdown structure presented as Figure 46. The research evaluation procedure consists of establish-

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Insert Figures 45 and 46 about here

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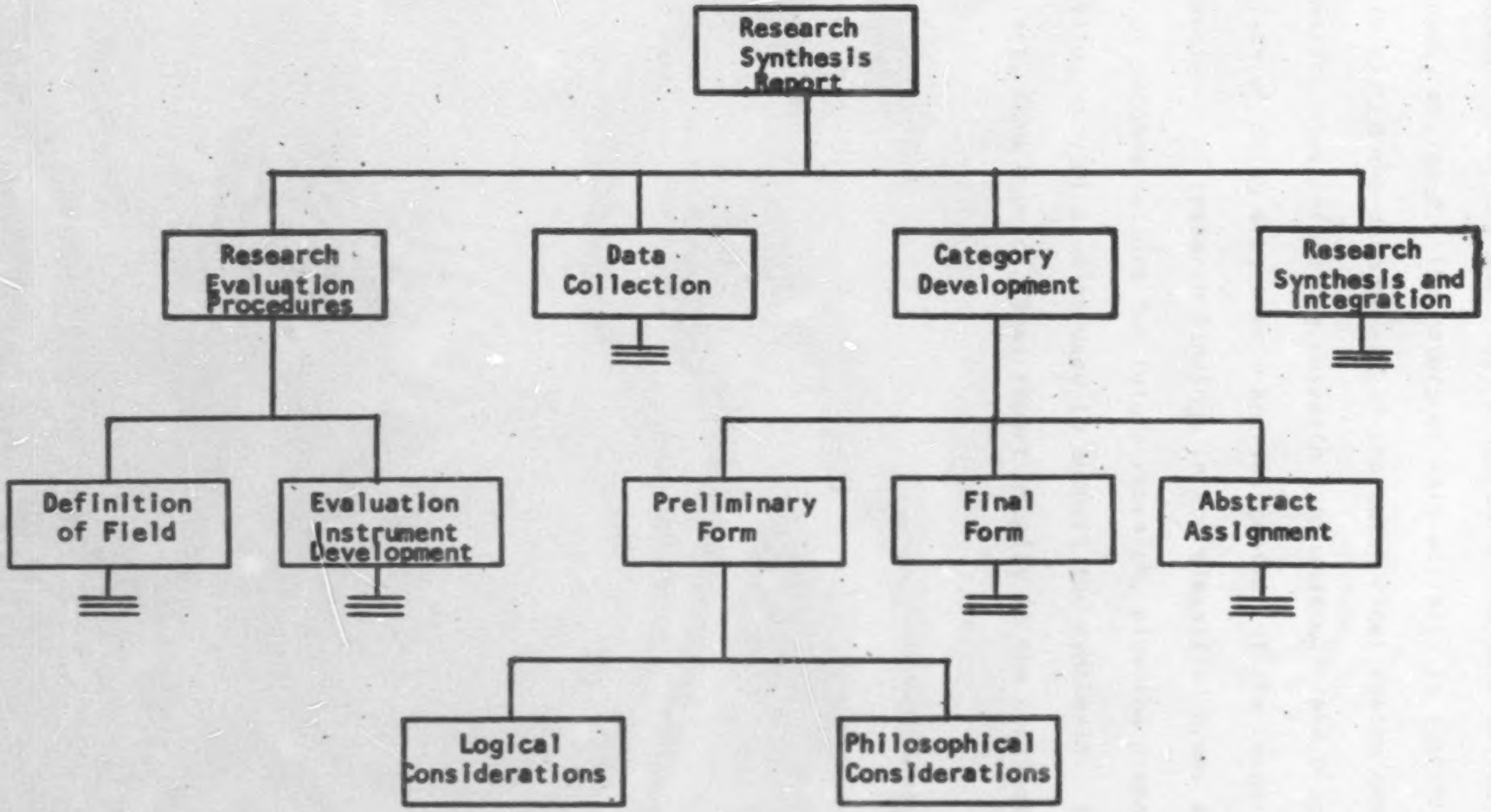
ing a definition of the field to be investigated. This is done by defining what will be considered as research and what topics are relevant to the investigation. Once these definitions become available, the field will then be defined. The development of an evaluation instrument is based upon a review of existing research evaluation techniques followed by the construction of a format for abstracting and evaluating the research. The activity of data collection consists primarily of compiling an initial list of studies appearing in published literature as well as determining their existence in unpublished form. Once [illegible] research reports have been identified, activities are undertaken to procure the necessary documents by use of inter-library loan facilities, microfilm purchase, and similar sources. Once the studies have been received, abstracts are then prepared. The activities involved in data collection are conducted largely in parallel. That is, the procurement and abstraction constitute an on-going process until such time as the project staff feels that this activity should terminate and succeeding activities begin. Further, as one study is reviewed it often leads to the identification, procurement, and abstraction of additional studies. To effectively synthesize the research, some type of categorical scheme needs to be developed so that the studies can be placed according to the variables of interest. A preliminary form or outline of the categories is derived by giving careful consideration to logical and philosophical aspects relating to the defined field. After a review

Figure 45. Tabular Work Breakdown Structure for Research Integration Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
Research Synthesis Report	Research Evaluation Procedures	Definition of Field	Relevancy Definition Research Definition
		Evaluation Instrument Development	Review of Research Evaluation Technique Research Abstraction and Evaluation Form
	Data Collection	Bibliographic Listing	Published Material Unpublished Material
		Research Report Procurement	Microfilms Inter-Library Loan
		Abstract Preparation	
	Category Development	Preliminary Form	Logical Consideration Philosophical Considerations
		Final Form	
		Abstract Assignment	
	Research Synthesis and Integration	Synthesis of Research Findings	1. Data Collection 2. "Like" Studies Summary
		Recommendation for Future Research	
		Annotated Bibliography	

Figure 46. Pictorial Work Breakdown Structure for Research Integrative Project


Research Synthesis Report
Research Evaluation Procedures
Data Collection
Category Development
Research Synthesis and Integration
Definition of Field
Evaluation Instrument Development
Preliminary Form
Final Form
Abstract Assignment
Logical Considerations
Philosophical Considerations

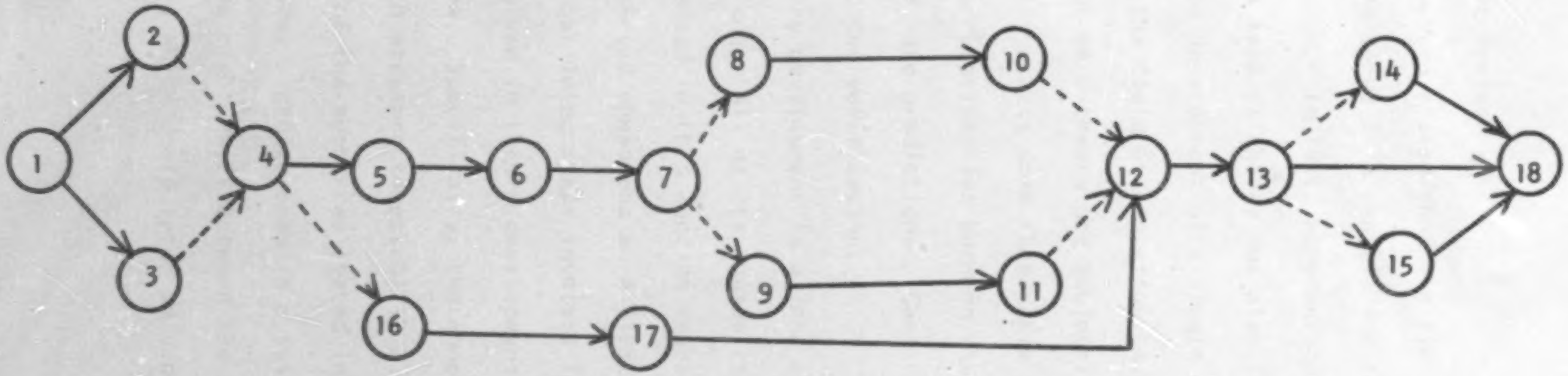
of this preliminary categorization scheme, a final system is established. Once this has been accomplished, the abstracts prepared in the data collection phase then can be properly assigned. The nature of this activity is such that once the project is initiated the development of the categorical system can then begin, but it must be established before the research synthesis can take place. The final work consists of doing a synthesis and integration of the research which consists of an analysis of research findings in the classified areas and topics, the preparation of recommendations for future research, plus the preparation of an annotated bibliography of studies used to support the synthesis. In the case of a funded project, some type of final report usually is the concluding activity.

The general flow of work described above is represented by the summary network appearing in Figure 47. A detailed network is not shown because uniqueness of such types of projects would no doubt cause variation in the actual procedures.

Insert Figure 47 about here

Detailed sub-networks could be outlined also for each of the major gross activities represented on the summary network. As represented here, the initial activities of defining the field would commence once the project has started followed in turn by the development of the evaluation procedures and the initial bibliographic listing. Once these are accomplished, documents can be procured and abstracted. Concurrent with these activities can be the development of the categorical system and the assignment of abstracts. It should be noted that the procurring of documents, the abstracting process, and assignments of abstracts constrain the synthesis of research findings. As the synthesis is being conducted, recommendations can be made for future research as well as preparing the annotated bibliography. Once these three activities have been accomplished, the project can be considered terminated except if there is a desire to include activities associated with the preparation of the final report.

Figure 47. Summary Network for Research Integration Project



Event Identification

1. Project Start
2. Complete Relevancy Definition
3. Complete Research Definition
4. Start Evaluation Instrument
5. Complete Research Evaluation Instrument Review
6. Complete Abstract and Evaluation Form
7. Complete Initial Bibliography List
8. Start Procurement
9. Start Abstracting
10. Complete Procurement
11. Complete Abstracting
12. Start Abstract Assignment
13. Start Synthesis and Integration
14. Start Recommendations for Future Research
15. Start Annotated Bibliography
16. Start Preliminary Category Development
17. Start Final Category Development
18. Project Complete

Theory Development Project

It has often been stated that the field of education lacks an integrative theory which would serve as a vehicle for the explanation and prediction of the learning process. In fact, many persons in education say that it suffers not only from the lack of theory but also from a multiplicity of theories which in turn hamper the development of a single unified theory. Consequently, many investigators in the field of education have attempted to conduct projects leading to the development of a theory and subjecting it to empirical test. Theory development usually starts some observable phenomena followed by a process of establishing interrelationships between the data collected to form explanations of the events and make predictions. Once established, the theory is subjected to empirical test for verification.

Because theory development is a long time activity the establishment of a general model to cover all of its phases is somewhat difficult. Hence, the model to be presented in this section represents a project designed to establish a taxonomy of observed phenomena as a first step in developing a theory. It is anticipated that outlining steps involved in such a project would be of value for projects involved in theory development - that of collecting and classifying observed phenomena. Specifically, the model presented represents the work done in connection with attempts to establish a taxonomy of teacher-classroom behavior (7). The intent of the author as stated in the proposal, was to observe teacher classroom behaviors, organize them in a systematic manner in order to determine what relationships might exist between the observed elements, and then to establish a theory which could later be subjected to verification.

To achieve the major goal of the project, three major work units could be identified. The first unit consisted of establishing the types of data constituting teacher-classroom behavior. To accomplish this activity, the investigators proposed to review existent teacher behavior classification schemes concurrently with a review of such schemes developed in other social process areas. These two activities were to result in the preparation of a working paper describing the various taxonomies. The working paper was then to be submitted to a series of experts for their reactions. The reaction papers prepared by the experts were to be distributed to all other reviewers for their consideration.

Upon completion of the above activity, an effort was to be made to synthesize a single taxonomy and resultant paradigm. The activities here consisted of conducting a seminar for further consolidation of the taxonomies. A synthesized taxonomy was then to be developed by extending existing taxonomies to cover gaps and looking at logical interrelationships existing between them. The accompanying paradigm was to be developed by identifying the variables to be included and providing working or operational definitions for each of the variables.

Upon completion of the taxonomy and paradigm it was to be subjected to empirical tests by using it in a series of filmed classroom situations and live classroom situations. From these two activities, necessary modifications and revision were to be made in the final taxonomy.

The tabular work breakdown structure for this project is presented as Figure 48 with the pictorial work breakdown structure presented as Figure 49. In the latter,

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Insert Figures 48 and 49 about here

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only the intermediate work package of test situations has been further broken down into more specific work packages. The network is presented in summary form as Figure 50. The flow of work as represented by the network shows that the activities

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Insert Figure 50 about here

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associated with determining the types of teacher behavior which might be included in the taxonomy by a review of existing educational and related literature were to be done initially followed by a review of existent taxonomies by the experts. The development of the synthesized taxonomy and paradigm, including the seminar held for face-to-face discussion, was followed by the synthesized taxonomy and accompanying paradigm. The final major unit work consists of trying out the synthesized taxonomy in test situations. In view of the results obtained in the test situation, the taxonomy was to be modified and revised.

Figure 48. Tabular Work Breakdown Structure for Teadher Behavior Taxonomy Project

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
Teacher Classroom Behavior Taxonomy	Teacher Behavior Data Analysis	Working Paper on Taxonomies	Review of Teacher Behavior Systems Review of Social Process Fields
		Working Paper Review	Expert Selection Working Paper Distribution Expert Review Distribution of Reaction Papers
	Taxonomy and Paradigm Development	Review Seminar	Seminar Plans Seminar Seminar Summary
		Synthesized Taxonomy	Extension of Taxonomies Logical Interrelationships
		Paradigm Development	Variable Identification Variable Definitions
	Taxonomy Test and Modification	Test	Observations Facilities Film Observation Classroom Observation
		Modification	Assess Film Reports Assess Classroom Reports

Figure 49.· Pictorial Work Breakdown Structure for Teacher Behavior Taxonomy Project

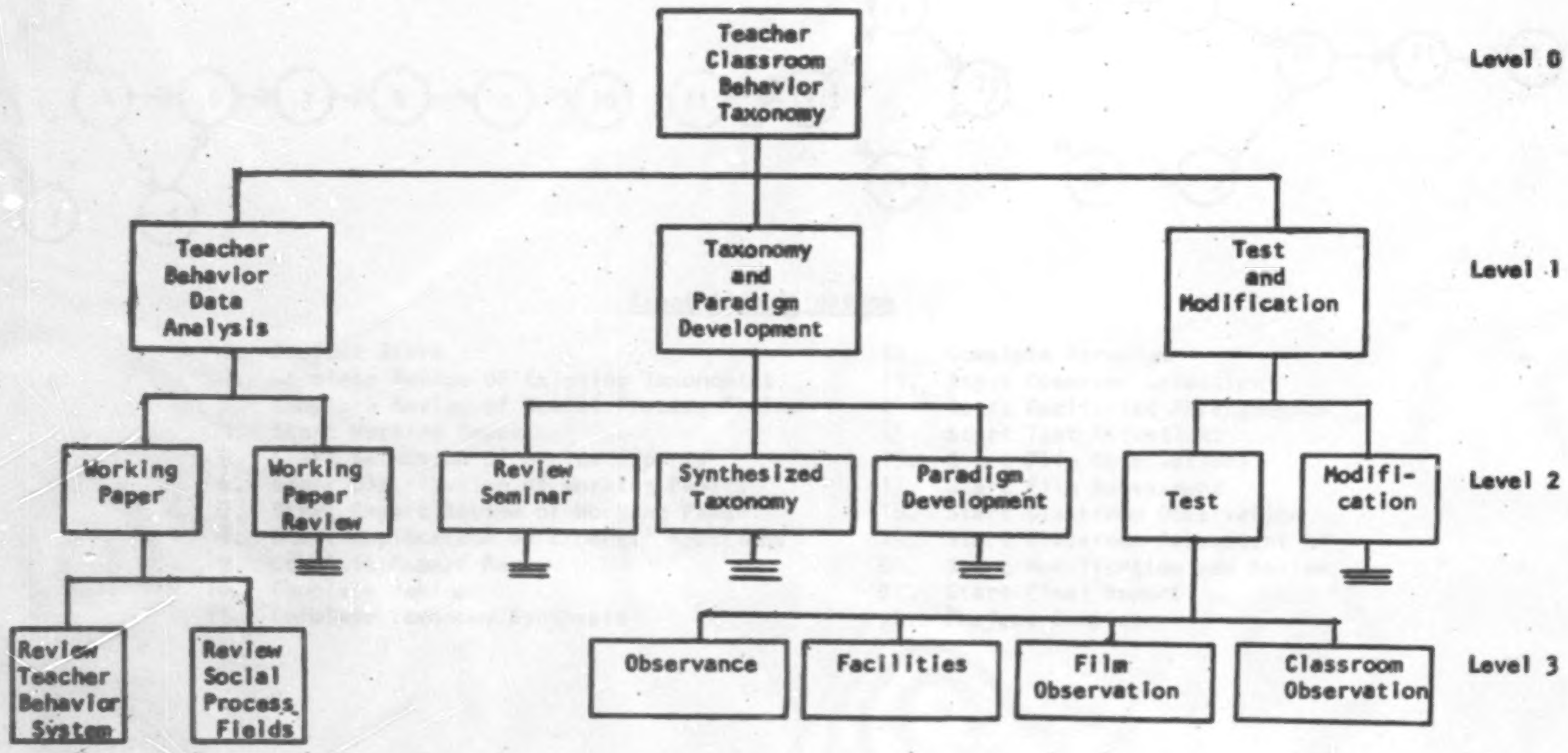
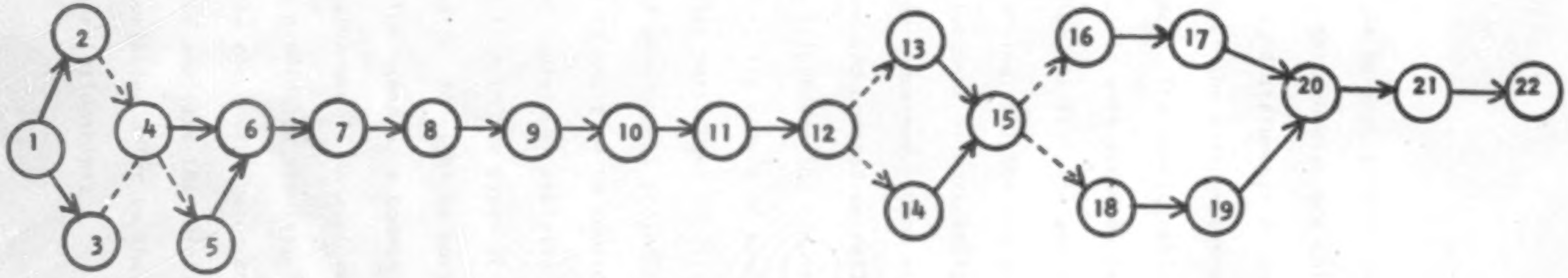

Teacher Classroom Behavior Taxonomy
Level 0
Teacher Behavior Data Analysis
Taxonomy and Paradigm Development
Test and Modification
Level 1
Working Paper
Working Paper Review
Review Seminar
Synthesized Taxonomy
Paradigm Development
Test
Modification
Level 2
Review Teacher Behavior System
Review Social Process Fields
Observance
Facilities
Film Observation
Classroom Observation
Level 3

Figure 50. Summary Network for Teacher Behavior Taxonomy Project



Event Identification

1. Project Start
2. Complete Review of Existing Taxonomies
3. Complete Review of Social Process Fields
4. Start Working Paper
5. Start Selection of Review Experts
6. Start Distribution of Working Papers
7. Start Expert Review of Working Paper
8. Start Duplication of Experts' Reactions
9. Complete Expert Review
10. Complete Seminar
11. Complete Taxonomy Synthesis
12. Complete Paradigm
13. Start Observer Selection
14. Start Facilities Arrangements
15. Start Test Situations
16. Start Film Observations
17. Start Film Assessment
18. Start Classroom Observation
19. Start Classroom Assessment
20. Start Modification and Review
21. Start Final Report
22. Project Complete

Summary

It should be kept in mind that the work breakdown structures and networks presented in this chapter are only illustrative and, therefore, should be considered as rigid statements of the work to be done. Additional levels could be added to any of the work breakdown structures presented to further detail work of the project. The configuration and content of a project's work breakdown and the specific work packages to be identified vary depending upon such considerations as the (1) size and complexity of the project, (2) the time available for planning, (3) the degree of uncertainty involved, (4) the project director's judgment of work assignments, and (5) the structure of the various organizations concerned. Once established, a work breakdown structure must be maintained and updated to reflect the changing situation. Further, no attempt was made to illustrate the time estimates involved in doing the several activities since the specific nature of each research and development project requires time estimates particular to it. As experience is gained in managing educational research and development projects using PERT, perhaps data can be accumulated with regard to the time to complete activities thus giving grounds for better estimates of individual activity times and total project time for future projects.

In addition to the types of research and development activities presented in this chapter, it might be possible to generate models for other kinds of research activity. For example, a common type of research activity are prediction studies where extensive use is made of correlational analysis, as in the case of academic performance prediction studies. Another common research activity is ex post facto studies where the investigator collects data in terms of selected hypotheses and questions and analyzes the relationships existing in the data to see if certain conditions existing prior to the collection of the data could be considered as causing the relationships.

It should also be noted at this time that the educational applications of PERT are not restricted solely to research and development activities. It can and has been used in project-type activities such as the development and establishment of a junior college, installation of a computer system for a school district, and the reorganization of an administrative structure at the university level. An excellent example of a PERT application in the junior college field is Benson's network reflecting the sequence of activities involved in establishing a new junior college (5). Such types of projects usually meet the several criteria for PERT implementation as outlined in Chapter 4.

It is generally recognized by management specialists, however, that PERT is most suitable for research and development activities and not routine or production-type projects.

Chapter IV

Implementing PERT on Educational Research and Development Projects

The purpose of this chapter is to outline some practical consideration on the actual implementation of PERT on a project. It is not possible to cover all contingencies of implementation but some guidelines derived from practical experience will help to make the process of implementing easier.

Deciding to Use PERT

The PERT technique can be applied to almost any project where logical planning is required. Applications can be made to a one-man project or to a project involving many persons, institutions, or agencies. The decision as to whether or not PERT can be used for a particular application should be made on the basis of several criteria.

First, there must be a specified end objective the accomplishment of which can be determined. Repetitious activities, such as student registration procedures, are not the kinds of projects for which PERT is most useful. A project designed to develop a new registration procedure to be ready by a certain date would be a more typical application. It is possible to derive some benefit from applying PERT to repetitive processes in order to determine the most efficient way to operate. For example, registration procedures might be diagramed or networked to determine if the optimum logic or sequence were being developed. An application of this type is illustrated in a study on registration procedures of Syracuse University reported by Smith (22).

A second criterion is whether or not some schedule date or deadline must be met. If there is no particular need to reach an end objective on schedule, one need not be concerned with the management of time. Projects funded by agencies which have definite directed dates for completion of the project are most suitable for PERT application.

A third criterion is the degree of project complexity. It is difficult to indicate exactly how complex a project should be before implementing PERT but in general projects involving one or two persons over a period of approximately two months with a network consisting of maybe 20 to 25 events might represent a minimum complexity. No objective standards have been truly set, however, for this criterion. As the complexity of the project increases, the need for PERT increases correspondingly.

A fourth criterion is the degree of uncertainty existing about the definition of some or all of the program elements. If the project is largely one possessing the "once-through" characteristic, PERT is then quite applicable. If the project, however, is one which is rather routine and standardized and there is much experience with regard to the operations to be carried out and their time sequence, then PERT probably is not applicable. In some cases, PERT might be used in the initial research and development activities and then after production-type items are developed some other management system might be employed to plan and control the operation.

An additional consideration as to whether or not PERT can be effectively applied or implemented on a project must relate to the experiences that project managers and other personnel have with PERT. Agencies utilizing PERT do so in different ways. Some have technical PERT specialists functioning in a staff capacity to assist in all operations except decision-making while others train line personnel to implement the technique. In any case, project personnel should have an adequate orientation before trying to employ the technique. A minimum type orientation would consist of approximately eight hours of lecture and practical exercise. The availability of a PERT specialist would be also helpful in the early stages of implementation.

Time of Implementation

The original development of PERT concentrated upon its use as a technique to ascertain the progress of a project or program as is indicated by its title-Program Evaluation and Review Technique. During the implementation of the original PERT process, it became readily apparent that the technique had value for project control and would serve as a valuable tool in the planning of projects during the program definition or proposal preparation phases. Consequently, PERT is being employed more and more as both a planning and controlling tool.

It is highly recommended, therefore, that the concepts and principles of PERT be utilized during the process of preparing research and development proposals before their submission to a funding agency. The value of such an application lies not only in deriving a time schedule for the project but more importantly it can serve as a method for checking the logic as well as identifying the necessary activities of the plan to be carried out along with their sequence and dependency. A review of the reasons for project proposal rejection would reveal that a large proportion of them are not funded because of inadequate description of the procedures to be carried out. Such a condition usually represents insufficient prior attention given to the actual techniques and procedures to be utilized in conducting the research. Careful planning of a research project requires considerable time. In fact, the planning of a research and development project may actually require more time than the actual conduct of the research.

The construction of a work breakdown structure and a correlated network during the early stages of project planning is of value in that it can identify program elements that might be overlooked as well as to determine the sequence of work and the constraints imposed upon subsequent project work by the completion of earlier activities. The employment of PERT would also serve as a valuable communication tool to the person reviewing the proposal for funding. Communicating the processes of the project by use of a network can present quickly to a reader the logic of the plan to be followed and whether or not the researcher has given consideration to necessary interrelationships. Further, the end products of the project would be more readily identified. Usually such end products take the form of a final report but it is not unusual to have final end items consisting of such products as curriculum guides, instructional films, textbooks, and similar items.

One should not be too concerned about the possible danger that establishing a network in the planning stages of the project would result in a freezing of the project work and thus not permit the opportunity to investigate promising leads as they might develop during the project. It is important to understand that PERT is a dynamic system. That is, any research and/or development project will probably not go as originally planned and necessary changes may occur both in the final end item and the process of arriving at the end item. As the project progresses, work breakdown structures and networks can be supplemented to accommodate program changes provided that such changes will not result in an overrun of total project cost in a fixed price contract situation nor seriously modify the final end item for which the contract was awarded. Such major program redefinitions usually have to be cleared by the funding agency before being incorporated into the project framework.

In summary, PERT can be used in both the planning and operational phases of a research and development project. Use in the planning stage usually results in a clearer definition of the project objectives as well as in procedures to be employed to reach the objectives. The use of PERT as a control tool has been demonstrated through its success on many and varied kinds of activities.

Network Construction

As noted in Chapter 2, the network is the basic feature of the PERT technique. It portrays graphically the tasks to be done, the order in which they are to be done, and serves as a communication tool to other staff members. It is important, therefore, that the network be carefully drawn.

Since the drawing of a network requires constant revision and changes, simplified procedures for establishing the first or original network should be employed. Experience has shown that using large sheets of newsprint, blackboard, or large sheets of acetate-covered cardboard and grease pencil are quite useful techniques. Engineering fade-out vellum is the ideal paper. PERT templates also facilitate networking. The employment of "activity" cards in preparation of networks is also useful. This procedure consists of identifying each project activity on a separate 3" x 5" card. Then the cards are laid out on a large table, working from the end objective back to the start of the project. The cards can be moved about quite freely in order to make sure the proper dependencies and interrelationships are established. Once the cards have been finally placed, a hand copy of the network is then prepared using the cards as activity lines and putting event circles at start and end points. After the network is drawn, the events are numbered and these numbers placed on the original activity card. If an additional step of time estimating is taken at this time, that information can also be put on the network as well as on the cards. An activity card such as shown in Figure 51 could be used as a source document for keypunching since the basic information needed for most computer programs is available on the card. One should not be discouraged if there seems to be many crossing lines and other conditions which do not make for a pretty network. One can always redraw these to show them in a better manner.

Insert Figure 51 about here

Figure 51. Sample Activity Card

PRED. EVENT NO.__________ **SUCC. EVENT NO.**__________

ACTIVITY______________________________________

Optimistic time (a) __________

Most likely time (m) __________

Pessimistic time (b) __________

Expected elapsed time (t_e) __________

(See Reverse Side for Detailed Description)

Network Processing

The processing of network computations in order to arrive at such information as Expected Elapsed Time, Earliest Expected Date, Latest Allowable Date, and Slack can be done either manually or by a computer. Manual procedures consist of using such devices as monographs, circular slide rules, and/or desk calculators. Several commercial firms have made momographs and slides available at a nominal cost useful in calculating the Expected Elapsed Time or t_e. The calculation of T_E and T_L which are essentially summation and subtraction processes can be done on a desk calculator. No definite network size has been established with regard to the practicality of hand computations. There seems to be a consensus that a network of 200 events or less can be satisfactorily handled by manual procedures. Networks larger than this size are generally regarded as being ones which can be handled by data processing techniques.

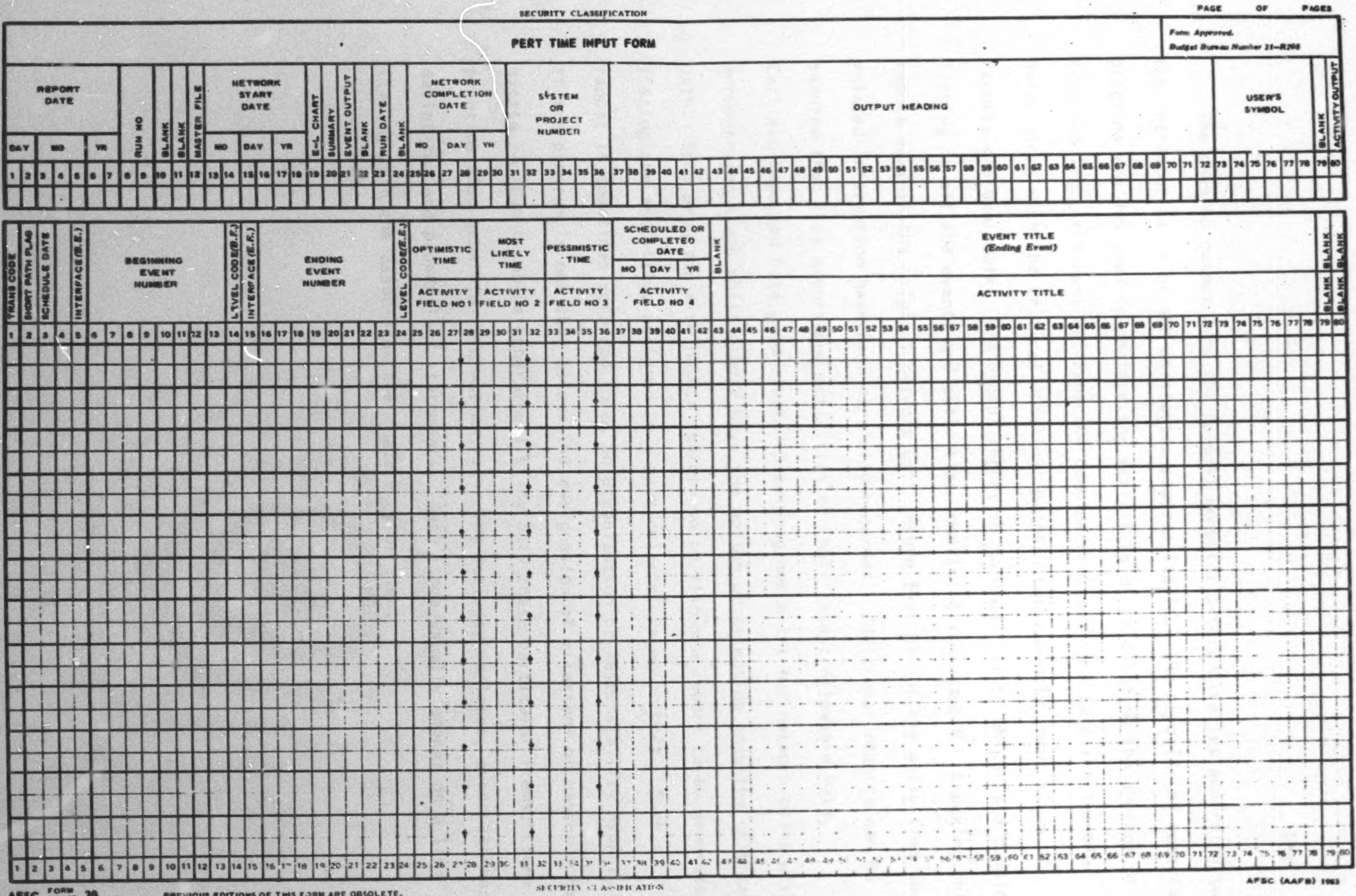
Numerous computer programs have been written for PERT computations by agencies using PERT and companies producing computers. The most comprehensive listing of PERT computer programs along with their individual characteristics appears in a document by Phillips and Beek (20). In addition to network size, another reason for using the computer is that the desired information can be obtained quickly and accurately. The general input data for computer processing consists of the following items:

A. Predecessor and successor event numbers
B. Activity descriptions
C. Single or three time estimates
D. Schedule and/or directed dates
E. Milestone event designation
F. Desired sorts (critical path report, etc.)

An input data sheet for the USAF PERT computer program is presented as Figure 52. It should be pointed out that some computer programs require that the event numbers be in sequential order while others take a random number sequence. A prospective user of a PERT computer program should examine it carefully in order to determine exactly what its particular characteristics are and the exact nature of input data requirements.

Insert Figure 52 about here

Figure 52. USAF PERT Time Input Form



SECURITY CLASSIFICATION

PAGE OF PAGES

PERT TIME INPUT FORM

Form Approved.
Budget Bureau Number 21–R298

REPORT DATE (DAY, MO, YR)
RUN NO
BLANK
BLANK
MASTER FILE
NETWORK START DATE (MO, DAY, YR)
E-L CHART
SUMMARY
EVENT OUTPUT
BLANK
RUN DATE
BLANK
NETWORK COMPLETION DATE (MO, DAY, YR)
SYSTEM OR PROJECT NUMBER
OUTPUT HEADING
USER'S SYMBOL
BLANK
ACTIVITY OUTPUT

TRANS CODE
SHORT PATH FLAG
SCHEDULE DATE
INTERFACE (B.E.)
BEGINNING EVENT NUMBER
LEVEL CODE (B.E.)
INTERFACE (E.E.)
ENDING EVENT NUMBER
LEVEL CODE (E.E.)
OPTIMISTIC TIME / ACTIVITY FIELD NO 1
MOST LIKELY TIME / ACTIVITY FIELD NO 2
PESSIMISTIC TIME / ACTIVITY FIELD NO 3
SCHEDULED OR COMPLETED DATE (MO, DAY, YR) / ACTIVITY FIELD NO 4
BLANK
EVENT TITLE *(Ending Event)* / ACTIVITY TITLE
BLANK / BLANK
BLANK / BLANK

AFSC FORM JUL 63 30
PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE.
SECURITY CLASSIFICATION
AFSC (AAFB) 1963

The general output from the several computer programs varies according to the characteristics of the particular program itself. The majority of computer programs are designed to perform the activities of calculating the average or Expected Time, the Earliest Expected Completion Dates, and Latest Allowable Dates along with the Critical and limit paths. Consequently, many kinds of reports are available. One useful report is an "audit list" which is a complete listing of all the events and activities comprising the network. Checking this report against the original network will insure that all of the activities and related information have been carefully recorded. Additional reports can be secured that list events and activities by their Latest Allowable Date, Earliest Expected Date, and slack. Some programs print out network paths with accompanying slack while others have the option of selecting only the critical path. Some programs also have a feature which allows a report to be generated listing the activities assigned to a particular division or unit. Such a report is sometimes referred to as an Organization or Responsibility Report. If the program is one that allows the designation of milestone or master schedule events, a report can be generated listing only these particular items. Some programs also generate information regarding activity variance, event standard deviation, and probability statements. Such items usually appear on a line listing with the associated event activity or event.

The options available in many of the computer programs presents some problem in knowing which ones are most useful. It can be stated with some assurance that the most useful report is the Slack Path printout. This report shows the most critical path along with the several limit paths in a network. Since primary project revision consists of shortening the time on the critical path, this is the report that should be looked at first.

Most of the computer programs have built-in error messages. One of the most useful such messages is the loop detector. This message indicates that someplace within the network there is a circularity or a returning from a successor event back to an earlier predecessor event. In order to correct this error, the network must be inspected using the "audit list" report to find the loop. Other error messages reveal that the network is not complete. In preparing the input deck, perhaps one activity was inadvertently omitted and hence one pathway is incomplete. Another useful error message consists of identifying incompatible dates. For example, it may be that a completion date is assigned to an event whereas the preceding event has not yet been completed. Other error messages can be generated depending upon the particular computer program but the above are the most common types.

Careful attention must be paid to the preparation of data to be used in computer programs. A careful check must be made against the network to be sure that the event numbers are correct, the time estimates have been transferred correctly, and all of the activities have been listed. Careful inspection before submission to the computer will prevent many errors and insure the accuracy of the final data.

The cost of running or processing networks on the computer varies according to the size of the network and the amount of information desired in the form of output reports and the particular computer used. If a relatively expensive computer is to be used, networks should be a sufficient size to justify the cost. Relatively small networks are perhaps best processed on a small computer. Another decision as to whether or not a computer program should be used rests upon the amount of staff effort involved in manual versus computer processing as well as the timeliness and accuracy of the information desired. It is important to understand that one does not need to use a computer program with PERT but once the networks become large computer processing of the data appears to be the only feasible way to handle the data.

Reports

It is a generally recognized principle of management that reports submitted to project directors and/or managers should be relatively simple and yet convey essential information. Project managers should not be forced to look at voluminous data and detailed reports. The report presented must be of such a type that problem areas can be quickly identified. Reports presented to managers should either be in simple graphic form or narrative form. Common types of reports presented to top level management under the PERT technique are the Project Outlook Report, the E-L or Milestone Report, and the PERT Report Analysis.

The Project Outlook Report usually shows the degree to which the project is running ahead, behind, or on schedule. Such a report is presented as Figure 53. The E-L chart usually lists selected milestone and/or master schedule events and plots on a time line the Earliest Expected Date (E) and the Latest Allowable Date (L). A quick inspection of the chart reveals the amount of slack available between these two dates. An example of such an E-L chart is presented in Figure 54. The PERT Analysis Report consist of a narrative description of problems identified along with possible suggested solutions. Usually such a report is prepared by staff personnel within the project after careful analysis of the data generated manually or by computers. An example of such a report is presented as Figure 55. In this illustration, a problem is identified and possible impact noted, alternative solutions and recommended actions are presented. The manager is not committed to any of these alternatives but does have immediately available to him the thinking of persons working directly with the problem.

Insert Figure 53 about here

Insert Figure 54 about here

Insert Figure 55 about here

Figure 53. Project Outlook Report Showing Project Slack Condition

PROJECT OUTLOOK REPORT

Project: PERT Report Date: May 1965

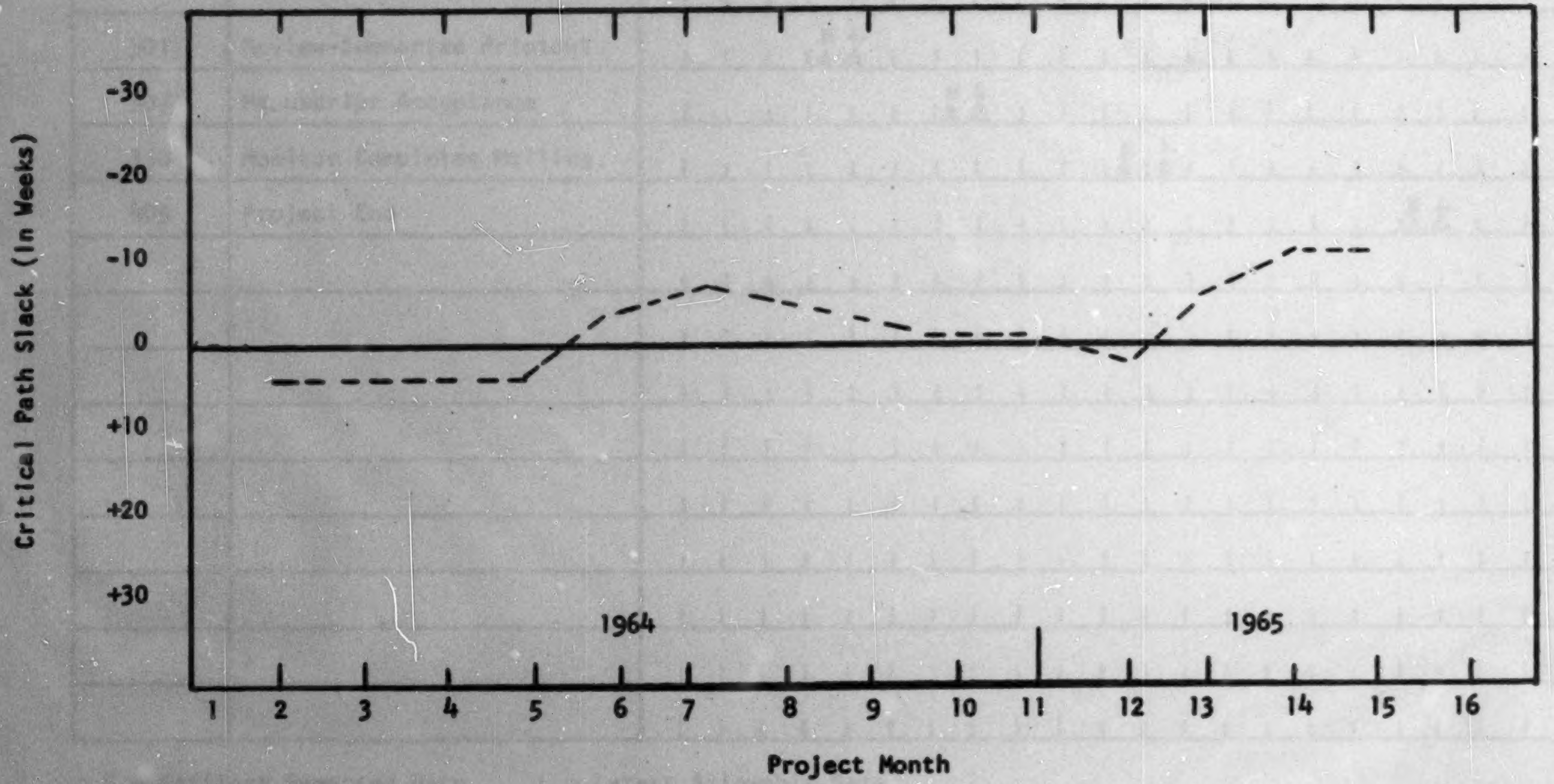
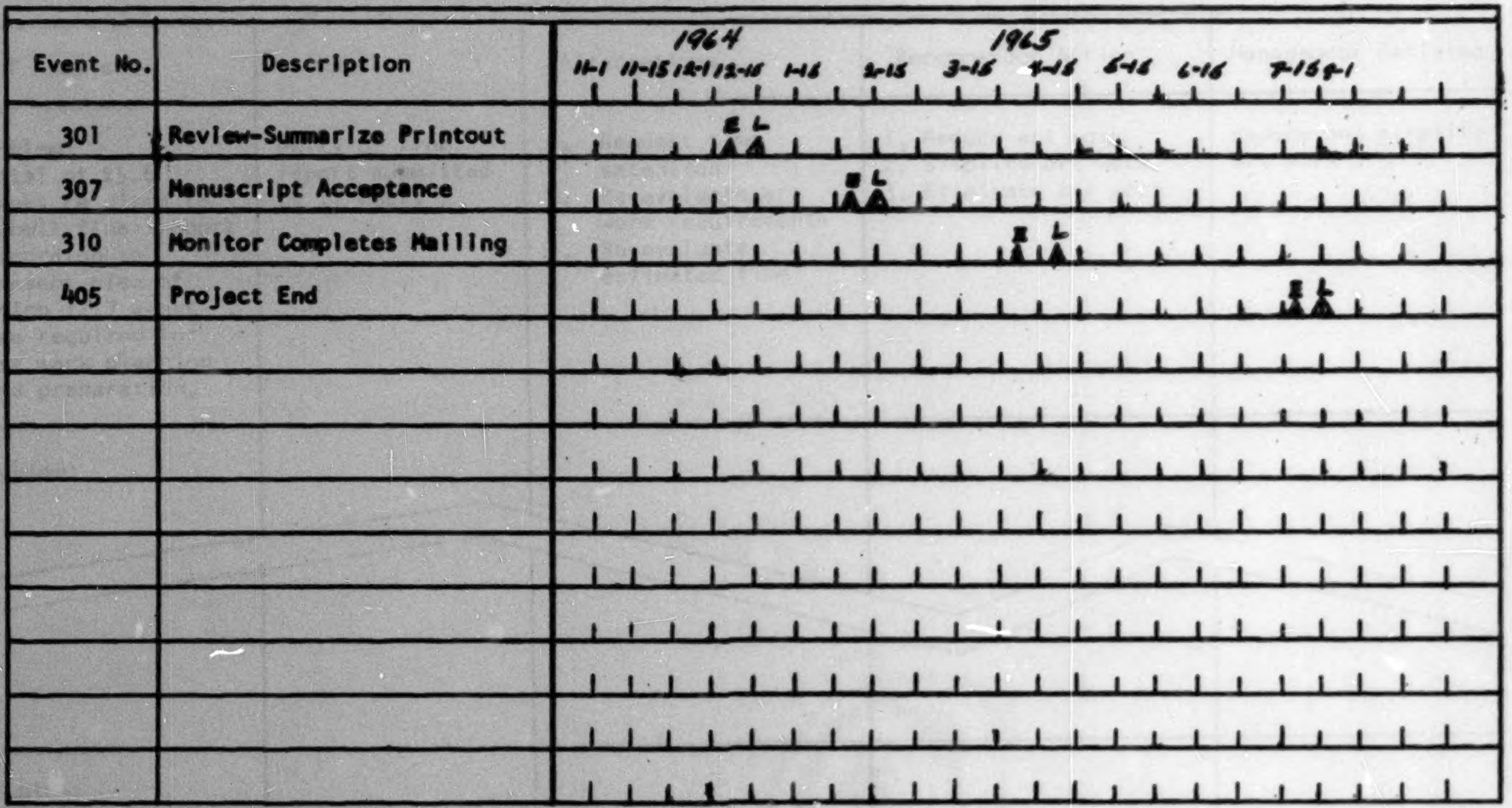


Figure 54. Illustrative E-L Report for a Project

MASTER SCHEDULE OR MILESTONE REPORT

Project G.E.D. Report Date 10-20-64 Page 1 of 1 Pages



Event No.	Description
301	Review-Summarize Printout
307	Manuscript Acceptance
310	Monitor Completes Mailing
405	Project End

E = Earliest Expected Date L = Latest Allowable Date

Figure 55. PERT Analysis Report for Management Review

PERT ANALYSIS REPORT

Project: PERT

Report Date: 5-21-65

PERT Analysis	Impact	Alternatives	Recommended Action	Management Decision
Problem: Total of 25.6 weeks required to submit final report according to present plan of which 12.7 weeks are required for art work planning and preparation.	Delay of final report submitted by 11 weeks	1. Request time extension 2. Re-evaluate art work requirements 3. Re-evaluate estimated time	1. Reduce art work 2. Simplify art work 3. Eliminate art work	Reduce and simplify art work
Problem:				
Problem:				

The frequency with which such reports are prepared and submitted to management vary from project to project. Some programs require bi-weekly reports while others require only monthly reports. Regardless of the frequency of reporting, the value of the report lies in its timeliness in reporting current conditions and the information it contains with regard to problem areas and possible solutions. Delays in developing reports should be avoided since late information about problems prohibits the manager from applying corrective actions.

Project Updating

As the project moves along, the initial plan is invariably altered. New activities may be added, work is completed behind or ahead of schedule, and the time estimates for on-going activities must be re-estimated. The process of revising the project plan (or network) is referred to as "updating" and involves the actions listed or described below.

The most basic step in project updating is the securing of time estimates for new activities incorporated into the plan, estimates for time to completion for activities now in progress, and possible revision of time estimates for work yet to be accomplished which can now be more accurately defined. In the case of new activities, the process of securing time estimates from responsible management personnel is the same as in the original time estimating procedure. Activities currently in progress will have consumed some of the originally estimated time and have further time to completion. A review of the work accomplished and yet to be done must be made in order to secure time estimates for completion of the activity. Notations made on the network as to the date of completion for an activity or the reaching of an event is a useful way of keeping track of activity completions. The project director or his associates should not trust to their memories as to the completion dates but rather develop a system of recording dates as suggested. As progress is made during the project, it is quite possible that activities yet to be done reflect time estimates based upon uncertainty associated with the nature of the task or an inability to define the tasks far enough ahead in order to give valid time estimates. Revisions in activities not yet initiated can be made at this time or they can remain as originally established until a succeeding update time.

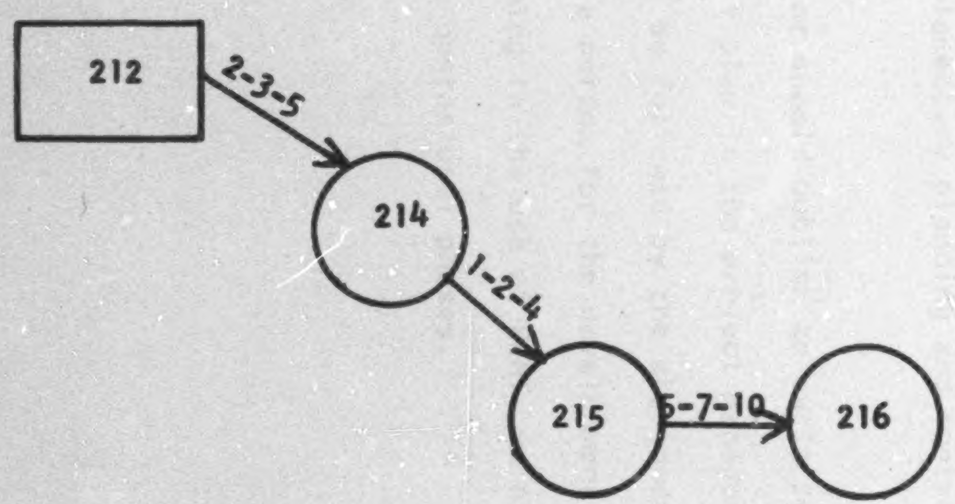
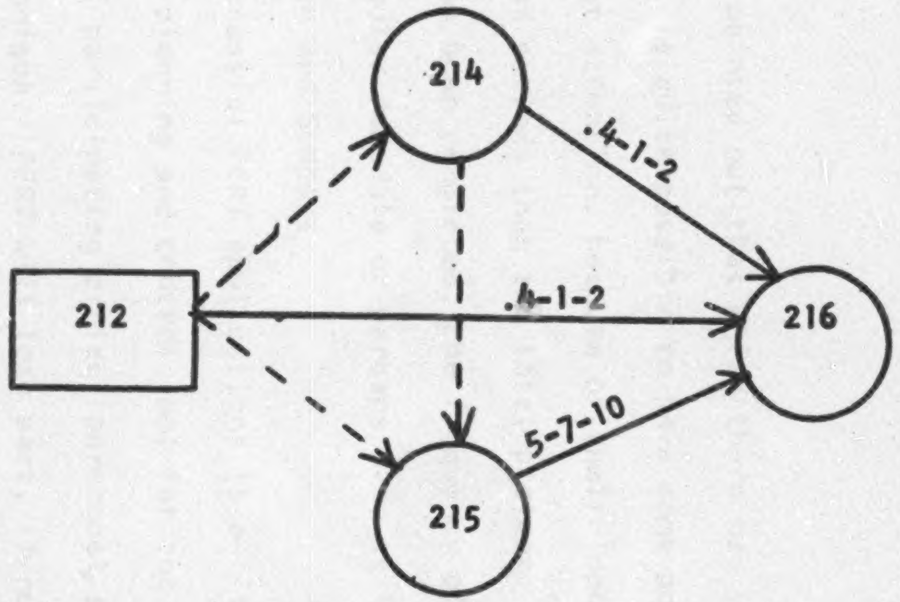
Updating not only involves the re-estimating of times as described above, but also includes certain mechanical procedures with regard to revising the graphical network. Major changes in the project plan should be incorporated into the graphical network as soon as possible. Relatively minor changes in the network plan need not necessarily result in a modification of the network at the particular reporting period. Such changes can be accumulated over a defined period of time and then incorporated into the network. A practical way of keeping track of both types of changes is the use of a "Was-Is" chart, a copy of which appears as Figure 56. Such a chart is useful in that it not only shows the project plan as it was and as now is but the necessary information with regard to changes in the data deck for computer runs can be transferred directly from the chart for keypunching purposes. Maintaining a file of such charts during the course of the project provides a useful way of studying the logic of the original plan once the project is completed. The project director should assign responsibility for incorporating necessary network changes to one of his staff in order to insure that the desired changes are properly recorded. Since the network provides a useful visual tool for noting project status, changes should be recorded as soon as possible after reviews are made.

Insert Figure 56 about here

Figure 56. Illustrative Was-Is Worksheet

NETWORK CHANGE WORKSHEET

Project G.E.D. Date of Report 9-1-64 Date of Change 9-4-64 Page 2 of 3 Pages

WAS	IS
 212 2-3-5 214 1-2-4 215 5-7-10 216	 214 .4-1-2 212 .4-1-2 216 5-7-10 215
212-214 Receive Semifinal Forms 214-215 Process Returns 215-216 Key Punch Returns	212-216 Receive Semifinal Forms 214-216 Process Returns 215-216 Key Punch Returns

☑ Old cards removed ☑ New cards punched and inserted ☑ Network drawing changed

It should also be pointed out that while there may be a normal interval of project updating, it is quite possible to have some portions of the project which require management attention, because of their importance or uniqueness, updated at more frequent periods than the total project. Once such a portion of the total network has been completed, the frequency of reporting may be incorporated into the regular schedule or perhaps even at longer intervals.

Management Participation and Support

Fundamental to successful PERT applications is a firm decision to use PERT as the management planning and control tool for the entire project. Having made this decision, all participating project personnel should receive proper instruction in the technique. PERT will lose part, if not all, of its effectiveness as a management tool as well as become a burden to the project if it is used as a supplementary planning and control system without full project management support.

The project director should publish an early policy statement setting forth the role PERT will play in the project management and control. The policy statement should be followed by the assignment of responsibility to an organizational unit or a person for the development of an implementation plan, provide personnel training in the use of PERT, maintaining and updating the program plan during the operational phases.

The purpose of this chapter, as well as the monograph itself, is to present the basic principles, procedures, and considerations involved in the implementation of PERT on a research and development program or project. The recommendations presented should not be considered as absolute guidelines or specific rules but rather as guidelines. In order to assist the person using PERT for the first time to make sure that the principal features of the system are considered, a PERT Implementation checklist is presented in Figure 57.

Insert Figure 57 about here

The steps involved have been divided into two general topics - Organizing for PERT Implementation and Operational Considerations. The first topic presents the activities to be considered during the preparation for use of PERT. The second topic presents, in general sequential order, the activities to be considered in the actual application from the establishment of the work breakdown structure through to periodic updating of the project plan. In using the check list, it should be kept in mind that the degree of application can vary depending upon such factors as contractor requirements, internal management requirements, and project nature, duration, and complexity. PERT is a flexible management technique and should, therefore, be adapted as needed for adequate project planning and control. Detailed descriptions of PERT implementation, considerations, and procedures can be found in the USAF PERT Implementation Manual (3), the PERT Fundamentals (19) textbook prepared by the PERT Orientation and Training Center, Washington, D.C., or the publications noted in the list of References and the Annotated Bibliography.

Figure 57. PERT Implementation Checklist

CHECKLIST FOR PERT IMPLEMENTATION

I. Organizing for PERT Implementation

  A. Prepare policy statement on management support and participation.

  B. Assignment of organizational responsibilities for PERT implementation and operation.

  C. Secure PERT guidance documents.

  D. Develop PERT implementation plan.

  E. Prepare procedures handbook for PERT implementation to include such topics as:

    1. Methods of preparing and transmitting input data during the original PERT application.

    2. Methods for providing updating information as a result of computer processing or hand calculations.

    3. Distribution system for output data and reports to persons having decision-making authority.

    4. Types of management reports to be employed.

    5. Establish frequency of reporting.

    6. System for network preparation including event numbering, standard activity descriptions, and designation of milestones.

    7. Data input and output formats (depending on computer used) to be employed.

  F. Conduct PERT training.

II. Operational Considerations

A. Work Breakdown Structure

1. Develop work breakdown structure consistent with project proposal.
2. Check to insure compatibility of work breakdown structure with proposal and contract items.
3. Check end item subdivisions to insure coverage of all work contained in the summary item from which developed.
4. Establish compatibility between work breakdown structure and the project organization.
5. Assign organizational responsibility for work packages.
6. Check to be sure work packages have well defined start and end points.

B. Establish Network

1. Develop master network to show general project plan.
2. Develop detailed network and sub-networks based upon the master network and project work breakdown structure.
3. Check events for uniqueness (i.e., occurring only once).
4. Check network for possible "loops."
5. Select project milestone events.
6. Identify interface events.
7. Check logic of final project network plan.
8. Adopt event numbering system (sequential or random depending on computer program to be used).
9. Secure time estimates for network activities.

C. Process Network Data

1. Enter directed date on network.
2. Transpose network event and activity data to keypunch input forms.
3. Audit input forms against network for completeness and accuracy.
4. Keypunch and verify PERT data.
5. Process data.

D. Analysis and Replan

1. Analyze computer output reports to note probability and slack conditions (i.e., problem areas).
2. Verify reasonableness of problem by use of cross checks to locate errors in input data or processing.
3. Analyze critical and limit paths to determine nature of constraints
4. Discuss possible problem areas with responsible organization or personnel for proposed solutions.
5. Document proposed solutions of and prepare for reprocessing.
6. Correct networks and reprocess data.
7. Establish internal schedule dates, consistent directed schedule dates, and Latest Allowable Dates.
8. Prepare reports and displays for management.

Figure 57. Cont'd

E. Update System

1. Note completion dates for work elements accomplished.
2. Secure time estimates for work elements in process.
3. Review and secure as needed time estimates for work elements yet to be initiated.
4. Incorporate management decisions into work breakdown structure and network.
5. Process data.

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Appendix A

A Glossary of PERT Terms and Symbols

Activity - The work effort involving time and resources required to complete a task or job to a given level of performance. It is represented on the network by an arrow and connects two network events.

Activity Network - A network that uses activities rather than events as the basic building block.

Activity Slack - The difference in time between Earliest Completion Date (S_E) and Latest Completion Date (S_L) for a given activity. Activity slack indicates a space in time within which an activity may be scheduled for completion. If the S_E for an activity is later than the S_L, then the activity has negative slack and either the current activities or the subsequent activities must be replanned or the project schedule will fall behind. If the S_L for an activity is later than the S_E, then the activity has positive slack, and additional time is available for performing the activity without causing the project schedule to fall behind.

Activity Time Estimate - The estimate of the time necessary to complete an activity in a specific manner. This time is specified in weeks and/or tenths of weeks.

Activity Variance - A statistical statement of uncertainty based upon three time estimates for an activity using the following formula:

$$\sigma^2_{t_e} = \left(\frac{a-b}{6}\right)^2$$

Arrow Diagram - This is a pictorial description of a plan showing the interrelationships of all required activities. It is also referred to as a network, a flow chart, etc.

Constraint - The relationship of an event to a succeeding activity whereby the activity may not start until the preceding event has occurred. The term "constraint" is also used to indicate the relationship of an activity to a succeeding event whereby an event cannot occur until all preceding activities have been completed. Constraints can be planned or real.

Critical Path - That sequence of events and activities that has the greatest negative or least positive slack, or the longest path through the network. It is represented by a double lined arrow.

Directed Date - The date of a specific accomplishment formally directed by the contract authority. It is usually represented by the symbol T_D.

Dummy Activity - A non time-consuming activity used to illustrate event dependency. It is not descriptive of work and is represented on the network by a dashed line arrow.

Earliest Completion Date - The earliest calendar date on which a work effort (work package, activity, or summary item) can be completed. It is usually represented by the symbol S_E.

Earliest Expected Date - The earliest calendar date on which an event may be expected to occur. It is usually represented by the symbol T_E. The Earliest Expected Date value for a given event is equal to the sum of the Expected Elapsed Times (t_e) for the activities on the longest path from the beginning of the program to the given event.

End Item - A major project objective, usually a deliverable item of the contract.

Event - A specific, definable, accomplishment in a program network, which is recognizable at a particular instant in time. Events do not consume time or resources. They are usually represented on the network by circles or squares.

Event Slack - The difference between the Earliest Expected Date (T_E) and the Latest Allowable Date (T_L) for a given event. If the T_E for an event is later than T_L, the event is said to have negative slack. When the T_L is later than the T_E, the event is said to have positive slack.

Expected Elapsed Time - The time which an activity is predicted to require based on the formula:

$$t_e = \frac{a + 4m + b}{6}$$

Expected Elapsed Time is usually represented by the symbol t_e and has a 50-50 chance of being equalled or exceeded in practice.

Event Variance - The sum of activity variances ($\sigma^2_{t_e}$) on the longest path to an event.

Flow Chart - A pictorial description of plan showing the interrelationships of all required events. It is also called a network, arrow diagram, etc.

Initial Event - An event which signifies the beginning of one or more activities on a network.

Interface Event - An event signalling a necessary transfer of responsibility, information, or end items, from one part of a plan to another.

Interface - An interface defines the relationship that exists between various areas of any work effort. The interface ties together the events and activities within one area of work effort that constrains completion of events and activities in another area of work.

Latest Allowable Date - The latest calendar date on which an event can occur without delaying the completion of the program. It is usually represented by the symbol T_L.

Latest Completion Date - The latest calendar date on which a work effort (work package, activity, or summary item) can be scheduled for completion without delaying the completion of the program or project. It is represented by the symbol S_L.

Limit Path - Any path containing negative slack other than the Critical Path. The Critical Path is the most limiting path.

Milestones - Key program events the accomplishment of which are essential to the completion of the program. A milestone is usually represented on the network by a rectangle.

Most Likely Time - The most realistic time estimate of the time an activity might consume in the opinion of the estimator. It is usually represented by the symbol (m). This time would be expected to occur more times than any other time if the activity could be repeated many times under the same circumstances.

Negative Slack - That amount of time in excess of the available time on a particular slack path predicted to be required to reach the objective event.

Network - A flow diagram consisting of activities and events which must be accomplished to reach the program objective. The flow diagram shows the planned sequences of accomplishment, interdependencies, and interrelationships of the activities and events.

Objective Event - The end or terminating event of the network.

Optimistic Time - The time in which the activity can be accomplished or completed if everything goes extremely well. It is represented by the symbol (a). It is estimated that an activity has one chance in a hundred of being completed within this period of time.

Pessimistic Time - An estimate of the longest time an activity would require under the most adverse conditions. It is usually represented by the symbol (b). It is estimated that an activity would have one chance in a hundred of being completed within this period of time.

Positive Slack - The amount of extra time available to perform a series of activities in a particular path in support of the required completion date.

Predecessor Event - An event immediately preceding an activity arrow which signifies the completion of the previous activity and the start of a new activity.

Probability - A statistical statement of the likelihood of occurrence of a particular event in the network. It is represented by the symbol P_R.

Random Event Numbering - A numbering system in which events are numbered in any order.

Scheduled Completion Date - A date assigned for a completion of an activity or event for purposes of planning and control. It is usually represented by the symbol T_S. Where no specific date is assigned, S_E equals T_S.

Sequential Event Numbering - A numbering system where each event has a number that is higher than the number of any event which sequentially precedes it.

Slack - The difference between the Latest Allowable Date and the Earliest Expected Date (T_L-T_E). It is also the difference between the Latest Completion Date and Earliest Completion Date (S_L-S_E). Slack is a characteristic of the network paths. Slack may be positive, zero, or negative.

Slack Path - That path through a network along which all the events have the same amount of slack.

Spread - An interval of time expressed in plus or minus weeks and tenths of weeks about the expected time (T_E) for an event which has a 50 per cent probability statement.

Standard Deviation - A statistical statement of variability about the expected completion date of an activity. Common PERT practice uses a standard deviation equal to 1/6 of the difference between the Optimistic and Pessimistic Time Estimates.

$$\sigma = \frac{b-a}{6}$$

Successor Event - An event signifying the termination point of one activity or the start of a new activity.

Task - A related group of activities that clearly define a segment of a program. Small programs may be considered as one task while a system program may have a hundred or more. Tasks in a program are relatively stationary while activities are dynamic.

Time Estimate - An estimate of how long it would take to perform an activity, based upon technical judgment, experience, and knowledge of the job. Time estimates are not commitments or schedules.

Time Now - Current calendar dates.

Work Breakdown Structure - A family tree subdivision of a project beginning with the end objective and then subdividing this objective into successively smaller units. The work breakdown structure establishes the framework for defining the work to be accomplished, constructing a network plan, and summarizing the cost and schedule status of a project for progressively higher management levels.

Work Package - Work required to complete a specific activity or specific activities. The content of the work package may be performed by a single working unit or by several working units. Overall responsibility for the work package is usually assigned to a single individual or department.

Symbols

a - The Optimistic Time Estimate for an activity when three time estimates are used.

b - The Pessimistic Time Estimate for an activity when three time estimates are used.

m - The Most Likely Time Estimate for an activity when three time estimates are used.

P_R - Probability for an event or activity being completed on time.

S_E - Earliest calendar completion date for an activity or event.

S_L - Latest calendar completion date for an activity or event.

T_D - A date for the completion of a specific event or activity, formally directed by the contracting authority.

t_e - The Expected Elapsed Time for an activity.

T_E - Earliest Expected Date for an event or activity completion.

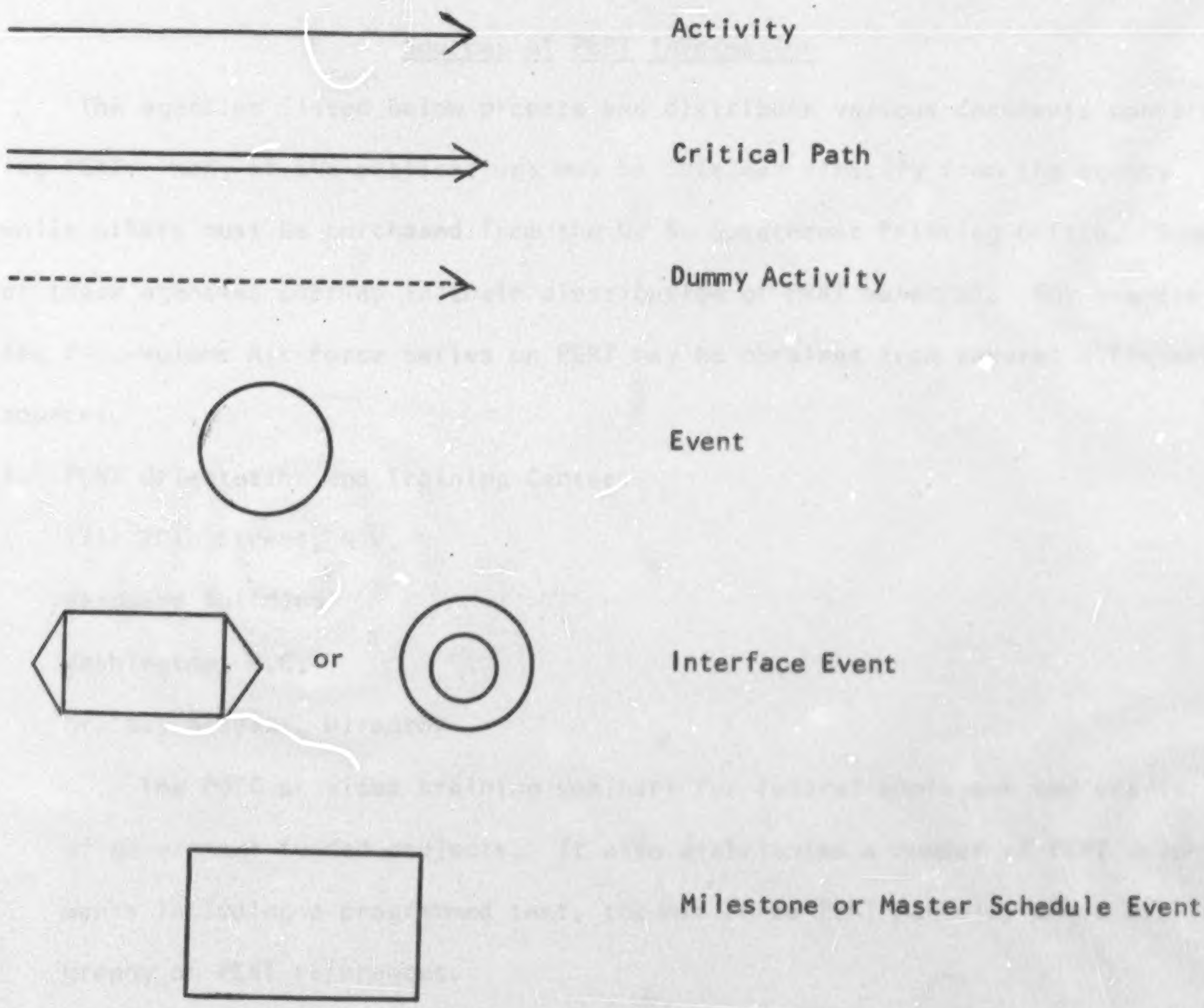
T_L - Latest Allowable Completion date for an event or activity completion.

T_{O_E} - Earliest Expected Date for the objective or final event.

T_{O_S} - Scheduled date for the objective or final event.

t_s - The Scheduled Elapsed Time for an activity.

T_S - The Scheduled Completion Date for an activity or event assigned for purposes of internal project control.


Activity
Critical Path
Dummy Activity
Event
or
Interface Event
Milestone or Master Schedule Event

Sources of PERT Information

The agencies listed below prepare and distribute various documents concerning PERT. Many of the publications may be obtained directly from the agency while others must be purchased from the U. S. Government Printing Office. Some of these agencies overlap in their distribution of PERT material. For example, the five-volume Air Force series on PERT may be obtained from several different sources.

1. PERT Orientation and Training Center
   1111 20th Street, N.W.
   Vanguard Building
   Washington, D.C.
   Mr. Guy A. Best, Director

   The POTC provides training seminars for federal employees and staffs of government funded projects. It also distributes a number of PERT documents including a programmed text, the Air Force PERT Manuals, and a bibliography of PERT references.

2. Defense Documentation Center
   Scientific and Technical Information
   Cameron Station
   Alexandria, Virginia

   The DDC distributes military reports prepared by Department of Defense contractors, a PERT report bibliography, and reports and articles from other sources. Distribution of military reports is generally restricted to companies or institutions having government funded projects.

3. Aeronautical Systems Division
   Air Force Systems Command
   Wright-Patterson Air Force Base, Ohio

   The AFSC issues basic documents on PERT/Time and PERT/Cost and reports of applications of PERT. The USAF PERT Manuals are also available from the AFSC. These five volumes cover PERT/Time, PERT/Cost computer application, and implementation of PERT.

4. U. S. Army Management Engineering Training Agency
   Rock Island Arsenal
   Rock Island, Illinois

   This agency provides training courses in project management techniques including the PERT/Time and Cost system. The courses are available to military and government personnel and contractors holding or submitting proposals for government contracts. This agency also issues documents concerned with the implementation of PERT including case problems in the application of the system.

5. Special Projects Office
   Department of the Navy
   Washington, D.C.

   The Special Projects Office makes available through the Superintendent of Documents, U. S. Government Printing Office Publications on PERT including a description of the initial application of PERT to the Polaris Program.

6. PERT Coordinating Group
Office of the Assistant Secretary of Defense
Washington 25, D.C.
Mr. A. William Buschman, Chairman

This group has the responsibility for coordinating PERT efforts within government and military agencies. Many of the documents and technical papers prepared by this agency are distributed by the POTC.

7. Government Printing Office
Superintendent of Documents
Washington, D.C. 20402

The documents listed below may be purchased by interested persons or organizations.

(1) An Introduction to the PERT/Cost System of Integrated Project Management - D217.2: P94/6

(2) Cost Reduction Through Better Management in the Federal Government Bureau of Budget - PREX 2.2: C82

(3) DOD and NASA Guide, PERT/Cost System Design - D1.6/2: P94

(4) DOD and NASA Guide PERT/Cost Output Reports, Supplement No. 2: P94/6, Vol I, II, III

(5) PERT Fundamentals in programmed instruction format, D1.2: P94/6, Vol I, II, III

(6) PERT Guide for Management Use - PERT Coordinating Group - DOD, D1.6/2: P94/2

8. The PERT Project
41 West 11th Avenue
School of Education
The Ohio State University
Columbus, Ohio
Dr. Desmond L. Cook, Director

The PERT Project is funded by The Cooperative Research Branch of the U. S. Office of Education. The project staff has prepared a series of bulletins on PERT which are available at no charge. A sample problem on PERT/Time is also available from the project.